EVALUATING THE USE OF CROWDSOURCING AS A DATA COLLECTION METHOD FOR BICYCLE PERFORMANCE MEASURES AND IDENTIFICATION OF FACILITY IMPROVEMENT NEEDS

Final Report

SPR 768

Oregon Department of Transportation

EVALUATING THE USE OF CROWDSOURCING AS A DATA COLLECTION METHOD FOR BICYCLE PERFORMANCE MEASURES AND IDENTIFICATION OF FACILITY IMPROVEMENT NEEDS

Final Report

SPR 768

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16. Abstract

This research developed a smartphone application called ORcycle to collect cyclists' routes, users, and comfort levels. ORcycle combines GPS revealed route data collection with new questionnaires that try to elicit cyclists' attitudes as well as comfort levels and factors that influence their perceived comfort and route choice. The new questionnaires were developed to better understand how cyclists' comfort levels are affected by route characteristics, route stressors, safety reports, cyclists' demographics, and cyclists' cycling attitude. Preliminary results show that many trip characteristics, route choice factors, route stressors and demographic variables are correlated with comfort levels. ORcycle is the first statewide deployment of a smartphone application to collect bicycle specific safety and crash data in addition to travel and comfort data. Potential applications that can take advantage of the ORcycle data include: comfort and route models, prioritization of network improvements, and crash and injury risk models.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

There is growing interest in formalized programs to collect data and understand bicycle activity. Bicycle transportation has become a central priority for transportation agencies invested in improving sustainability, livability, and public health outcomes. Constrained infrastructure spending has motivated research into understanding where bicycle improvements can yield the maximum net benefit in terms of increased ridership, comfort, and safety. The goal of encouraging new bicycle trips has also motivated research to understand what inadequacies may exist in current bicycle networks that could hinder the participation of less competent or confident cyclists. Crowdsourced data can be potentially used to gather data with finer granularity and to support the development of a new generation of bicycle related models.

1.1 RESEARCH OBJECTIVES

The first objective of this research project is to develop a smartphone application to fill some ODOT's data gaps regarding cyclists' routes, users, and comfort levels. While ORcycle is not the first smartphone application to collect bicycle travel data, it is the first statewide deployment of a smartphone application collecting bicycle specific safety data in addition to travel data. ORcycle has also added many user friendly features and increased the depth to which transportation planners and researchers can understand users' characteristics and their cycling preferences.

The second objective of this research project is to collect data to estimate cyclists Level of Traffic Stress (LTS) and data to prioritize infrastructure and safety improvements. The ultimate goal of this effort is to provide data and models that will support ODOT's planning efforts to improve bicycle facilities and policies.

1.2 REPORT ORGANIZATION

The reminder of this report is organized as follows:

- Chapter 2: A review of existing LTS and Level of Service (LOS) literature and estimation methods.
- Chapter 3: A summary description of existing bicycle and infrastructure smartphone applications.
- Chapter 4: A review of ongoing efforts to collect cyclists and GIS data at the state, metropolitan, and local level in the state of Oregon.
- Chapter 5: An introduction to the ORcycle smartphone application developed in this project and a review of its basic parts: trips, safety reports, crash reports, cyclists' socio-demographic data, and cyclists' attitude.

- Chapter 6: Descriptive statistics for the ORcycle data collected during the pilot study between November 2014 and March 2015. This section also analyzes sample bias and includes an exploratory study of LTS utilizing a subset of ORcycle data.

- Chapter 7: Final chapter that describes potential applications of the ORcycle data such as LTS modeling, prioritization of network improvements, crash and injury risk models, determination of Oregon's cyclists types, and improved route choice models. This chapter ends with lessons learned and final thoughts.

2.0 BLOS LITERATURE REVIEW

This section presents a review of the existing literature for BLOS and cycling stress levels. There are numerous methods that have been developed to evaluate various aspects of bicycling conditions. Unfortunately, definitions and terminology are not always consistent and there is a high degree of overlap among methods. The main references found within the body of literature are included herein in chronological order.

2.1 BLOS MEASURES

2.1.1 Bicycle Safety Index Rating (BSIR), 1987

The first systematic attempt to develop an evaluation method of bicycle facilities was made in 1987 by Davis at Auburn University *(Davis 1987)*. He aimed to "develop a mathematical model for indexing bicycle safety to physical roadway features and other pertinent factors". His evaluation tool was different from many that would follow in that it was more focused on safety than on perceived comfort. His Bicycle Safety Index Rating divided roadways into categories with similar roadway and traffic conditions. Davis's methodology depended on: average motor vehicle traffic, number of travel lanes, speed limit, width of outside lane, and pavement condition.

2.1.2 Bicycle Stress Level (BSL), 1994

The Bicycle Stress Level, developed by Sorton and Walsh *(Sorton and Walsh 1994)* in 1994, outlines a simplistic calculation of ordinal rating score (1 to 5) dependent on adjacent motor vehicle traffic volume, curb lane width, and motor vehicle speed. A facility rated "1" has a very low stress level and is considered reasonably safe for all types of bicyclists except for children under age ten. A facility rated "5" has a very high stress level and it is suggested that this facility may not be suitable for bicycle use.

Sorton and Walsh posited that it in general; (utility) bicyclists will choose bicycle routes that cost them the least amount of effort, both physical and mental. This not only means that they will choose the route with the flattest topography or smoothest pavement, but that cyclists prefer a route with less exposure to vehicle traffic and thus less mental stress. However, the level of stress a cyclist experiences is not objective nor is it the same for every rider. One of the primary ideas behind of level of stress methods is that different segments of the general population can ride comfortably at different levels of stress. Sorton and Walsh chose to segment the bicycling population primarily by age and cycling experience.

2.1.3 Road Condition Index (RCI), 1994

Epperson modified Davis's BSIR for use on roadways in Florida, focusing more on the comfort of roadways for bicyclists rather than trying to predict safety conflicts *(Epperson 1994)*. The result was the Roadway Condition Index. It adds several variables to Davis's original set:

parking presence, median presence, bicycle lane presence, topographical grade, and the presence of conflicts with drainage grates or rough railroad crossings.

2.1.4 Intersection Hazard Score (IHS), 1994

Landis's Intersection Hazard Score (Landis 1994) was the third method published in the Transportation Research Record in 1994. Like Sorton and Walsh's method (section 2.1.2), the primary assumption is that bicycle route choice is dependent upon bicyclist stress or their level of perceived hazard risk. It is dependent on several more data parameters and its output is a continuous number "score". The score is a function of the following variables:

1. Motor vehicle traffic
2. Number of through lanes
3. Useable width of outside lanes (includes bicycle lane and/or shoulder)
4. Land use intensity
5. Access point frequency
6. Pavement condition
7. Speed limit
8. Proportion of heavy vehicles

2.1.5 Bicycle Suitability Rating (BSR), 1995

The Bicycle Suitability Rating was Davis's update to his original method, with a greater focus on bicyclist comfort than on safety conflict prediction *(Davis 1995)*. His original method was first applied in 1987 for the city of Chattanooga, Tennessee, and was applied later by transportation planning agencies in other Southeastern states, such as Florida and Georgia *(Davis 1995)*. The various applications revealed the need for fine-tuning and validation. Davis conducted a test route evaluation in Atlanta, Georgia to see how the ratings of actual cyclists compared to the theoretical model; with the observed results being generally close to the model *(Davis 1995)*. However, the test route evaluation exposed other variables to take into account. The BSR adds the following variables to the original set: on-street parking presence, topographic grade, sight distance, adjacent land use, drainage grate presence, and rough railroad crossing presence.

2.1.6 Bicycle Level of Service (Botma's BLOS), 1995

Botma's Bicycle Level of Service or BLOS *(Botma 1995)* evaluates the traffic operations of separated bicycle facility segments. Botma's method is especially unique when compared to other methods in that it only evaluates off-street facilities: separated paths used by bicycles or separated paths used by bicycles and pedestrians. The evaluation method is dependent upon the path width, the user volume, the user composition (proportions of bicycles or pedestrians), and the user speeds. It is a tool used to evaluate optimal and less than optimal (i.e. congested) conditions on a bicycle path to see how the different variables affect the LOS rating. Similar to vehicle LOS, it is rated on an A through F scale. This method is the foundation of the Highway Capacity Manual (HCM) method for off-street facilities (more about HCM later in this section).

2.1.7 Bicycle Level of Service (Dixon's BLOS), 1996

Dixon's Bicycle Level of Service *(Dixon 1996)* considers facility type and riding environment characteristics to estimate a BLOS for a segment of bicycle facility. The BLOS score is a function of the following variables:

1. Facility type
2. Presence of parallel facility
3. Outside lane width
4. On-street parking presence
5. Access point density
6. Physical median presence
7. Sight distance restriction
8. Prevailing motor vehicle speed
9. Motor vehicle LOS
10. Facility maintenance condition
11. "Barrier" presence (e.g. bikeway discontinuities)
12. Multi-modal presence

2.1.8 Bicycle Suitability Score (BSS), 1997

The Bicycle Suitability Score was developed by Turner et al. *(Turner et al. 1997)* for the Texas Department of Transportation (TxDOT). Its primary purpose was to generate bicycle suitability criteria for developing a Texas bicycle map. It is a fairly simplistic calculation and outputs an ordinal rating (from -8 to 8) for a given bicycle facility. More specifically, the method only depends on adjacent motor vehicle traffic volume, shoulder width, posted speed limit, and pavement condition. The method is simple and especially useful for State DOTs since it is not data intensive *(Lowry and Callister 2012)*. The highest rating, "8", indicates that "the physical characteristics of the roadway are most likely desirable by intermediate to experienced bicyclists". The lowest rating, "-8", indicated that "the physical characteristics of the roadway are most likely undesirable by intermediate to experienced bicyclists".

2.1.9 Bicycle Compatibility Index (BCI), 1998

The Bicycle Compatibility Index was developed by Harkey et al. as part of a project sponsored by the Federal Highway Administration *(Harkey et al. 1998)*. The objective of the study 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 capability of specific roadways to accommodate both motorists and bicyclists" *(Harkey et al. 1998)*. The authors developed the BCI as an analogue to motor vehicle LOS for bicyclists, focusing on the idea of "stress levels" as opposed to operational characteristics. The methodology utilized videos of various bikeway segments, asking viewers to rate the segments "with respect to how comfortable they would be riding under the geometric and operational conditions shown"

(Harkey et al. 1998). After analyzing the results of the video reviews, the authors then used a regression model to calculate an index of the results that would be analogous to motor vehicle LOS. This index is a function of the following variables:

1. Presence of bike lane or paved shoulder
2. Bicycle lane width
3. Curb lane width
4. Curb lane volume
5. Other lane volume
6. 85th percentile motor vehicle speed
7. Presence of parking lane
8. Residential area
9. Truck volume factor
10. Parking turnover factor
11. Right turn volume factor

2.1.10 Bicycle Suitability Assessment (BSA), 2003

The Bicycle Suitability Assessment was developed by Emery and Crump in 2003 and is based on the BSIR and RCI *(Emery and Crump 2003)*. The BSA is a user-friendly form that can be filled out by engineers or members of the public for assessment of bicycle facilities *(Lowry and Callister 2012)*. This assessment is a function of the following variables:

1. Annual Average Daily Traffic (AADT)
2. Total number of through lanes
3. Posted speed limit
4. Outside lane width
5. Bike lane or paved shoulder width
6. Pavement condition
7. Presence of a curb
8. Presence of a "rough" railroad crossing
9. Presence of a storm drain grate
10. Presence of angled parking
11. Presence of parallel parking
12. Presence of a right-turn only lane
13. Presence of a center turn lane
14. Presence of a physical median
15. Presence of a paved shoulder
16. Bicycle lane marking
17. Topographic grade
18. Presence of frequent curves
19. Sight distance restriction
20. Presence of "numerous" driveways
21. Presence of "difficult" intersections
22. Industrial land use?
23. Commercial land use?
24. Presence of sidewalk

2.1.11 Rural Bicycle Compatibility Index (RBCI), 2003

The Rural Bicycle Compatibility Index was developed by Jones and Carlson as an alternative to the BCI for rural roads in Nebraska *(Jones and Carlson 2003)*, as the BCI was developed for urban and suburban roadway segments. The RBCI is a methodology calibrated using data from rural roads and it includes many variables common in many of the previous methods: traffic volume, traffic speed, volume of heavy vehicles, shoulder presence, intersection density, and space available in the cross section for bicyclists. The main difference between the RBCI and the BCI is that for the former, the regression used to compute the model coefficients was based on rural road data, and the latter on urban or suburban road data.

2.1.12 Compatibility of Roads for Cyclists (CRC), 2003

The Compatibility of Roads for Cyclist evaluation method was developed by Noël et al. *(Noël et al. 2003)* as a bicycle network evaluation tool for Quebec, Canada. It is based on data collected on rural roads in Quebec and the score is a function of the following variables:

1. Space available in cross section for cyclists
2. Shoulder pavement condition
3. Motor vehicle speed
4. Motor vehicle traffic flow
5. Heavy vehicle proportion
6. Presence of sand, gravel or vegetation on roadside
7. Driveway density
8. Presence of roadside ditches

2.1.13 Bicycle Intersection Safety Index (BISI), 2007

The Bicycle Intersection Safety Index was developed by Carter et al. *(Carter et al. 2007)* for the FHWA in 2007. The goal was to produce a methodology for collecting easily observable or measurable data at an intersection to produce a bicycle safety index value (and a pedestrian safety index value, though that is not considered here). This safety index could be used to prioritize intersections for bicycle improvements. Since different approaches to an intersection can have different safety levels, the BISI evaluates each intersection approach separately. "The study involved collecting data on pedestrian and bicycle crashes, conflicts, avoidance maneuvers, and subjective ratings of intersection video clips by pedestrian and bicycle experts" *(Carter et al. 2007)*. The bicycle data was sourced from intersections in Gainesville, FL; Philadelphia, PA; and Portland and Eugene, OR. The safety index is a function of the following variables:

1. Primary roadway motor vehicle traffic
2. Primary roadway motor vehicle speed
3. Presence of a turning vehicle potentially conflicting with the path of cyclist
4. Presence of a bike lane
5. Secondary roadway traffic volume
6. Presence of a traffic signal
7. Presence of on-street parking on the primary roadway
8. Number of traffic lanes that cyclists cross to make a right turn
9. Number of traffic lanes that cyclists cross to go through the intersection
10. Number of traffic lanes that cyclists cross to make a left turn

2.1.14 Bicycle Level of Service (Zolnik and Cromley's BLOS), 2007

Zolnik and Cromley's Bicycle Level of Service was developed in 2007 *(Zolnik and Cromley 2007)* and focuses on road segments characteristics that negatively affect bicycle safety. In their words, "Bicycle level of service refers to the ability of a road segment to accommodate motor vehicle and bicycle traffic safely" *(Zolnik and Cromley 2007)*. Their study related safety data collected from police, emergency medical service, and hospital databases to factors related to the physical design of the roadway segment.

2.1.15 Bicycle Level of Service (Jensen's BLOS), 2007

Jensen's Bicycle Level of Service was developed in 2007 *(Jensen 2007)* in a Danish Road Directorate sponsored study to quantify bicyclist stated satisfaction with road segments in Denmark. The goal was to provide a measure of how well urban and rural roads accommodated bicycle travel. The methodology showed video clips to randomly selected bicyclists and asked them to rate the road on a perceived safety and comfort level of one through six. After gathering nearly 8,000 video clips ratings, the ratings were used to estimate a cumulative logit regression model using 150 variables measured from the videos. The statistically significant independent variables were the following:

1. Adjacent land use
2. Motor vehicle traffic volume
3. Buffer width
4. Average motor vehicle speed
5. Presence of on-street parking
6. Width of bicycle facility
7. Width of outside lane
8. Presence of sidewalk on nearest roadside
9. Presence of bus stop
10. Number of lanes

2.1.16 Bicycle Level of Service (Petrisch's BLOS), 2007

Petrisch et al.'s Bicycle Level of Service was developed as part of a study sponsored by the Florida Department of Transportation (FDOT) *(Petritsch et al. 2008)*. It was based on rating data collected from user perceptions of both actual and virtual bicycle facilities. Explanatory variables were extracted from a regression model. The statistically significant independent variables were the following:

1. Motor vehicle traffic volume
2. Number of through lanes
3. Effective speed limit
4. Pavement condition (FHWA's five-point surface condition rating)
5. Proportion of heavy vehicles
6. Average effective width of outside through lane
7. Number of unsignalized intersections per mile

2.1.17 Bicycle Environmental Quality Index (BEQI), 2009

The San Francisco Department of Public Health (SFDPH) developed the Bicycle Environmental Quality Index to assess the bicycling environment for intersections and roadway segments in San Francisco neighborhoods. The main difference between this and other methods is that the weights assigned to the variables were generated from bicycle experts' ratings of importance (instead of direct ratings from randomized users or regression results). This index is a function of the following variables:

1. Bicycle lane markings
2. Bicycle lane slope
3. Presence of bicycle parking
4. Presence of bicycle scale lighting
5. Connectivity of bicycle lanes
6. Density of driveways
7. Presence of left turn bicycle lane
8. Sight distance
9. Presence of no turn on red sign(s)
10. Number of vehicle lanes
11. Presence of on-street parking
12. Pavement condition
13. Percentage of heavy vehicles
14. Presence of bicycle signage
15. Presence of trees
16. Adjacent land use
17. Presence of traffic calming features
18. Motor vehicle traffic volume
19. Motor vehicle speed
20. Width of bicycle facility

The BEQI introduces a number of variables that are not specific to a roadway or bikeway facility or its nearby environment. Some of the variables are more related to comfort at the route planning level (e.g. connectivity of bicycle lanes) and/or destination amenities (e.g. presence of bicycle parking).

2.1.18 Bicycle Quality Index (BQI) and Cycle Zone Analysis (CZA), 2010

Alta Planning and Design in a partnership with the Portland Bureau of Transportation (PBOT) developed the Bicycle Quality Index for use in the update of Portland's *Platinum Bicycle Master Plan*[1] *(Birk et al. 2010)*. It serves as an input for PBOT's Cycle Zone Analysis (CZA) efforts, which aim to divide Portland into zones based on several factors:

[1] For more information: http://www.portlandoregon.gov/transportation/44597

- Areas suited to capture large numbers of cycling trips
- Areas with the greatest potential increase in bicycle trips given existing conditions
- Areas that are best suited for strategic infrastructure investments
- Areas that may benefit from innovative bikeway treatments to maximize cycling potential

The CZA (network level) is a function of the following variables:

1. Bicycle facility quality
2. Road network density: average density (total length of road divided by area of zone) of the road network in the cycle zone.
3. Bicycle network density: average density (total length of bikeway divided by area of zone) of bicycle network in the cycle zone.
4. Permeability between zones: (a relative score of "permeability" is given to the barrier (e.g. a river) between zones, and this is normalized by the length of the barrier)
5. Connected Node ratio: measures network connectivity; it is calculated by dividing the number of four plus-way intersections by the number of three-way intersections and cul-de-sacs.
6. Average road segment slope: the average slope (measured in degrees) of all roadway segments in a cycle zone.

The authors' definition of a cycle zone is the following: "A cycle zone is an area that exhibits similar or homogenous cycling characteristics within its boundaries. Generally, a cycle zone is defined by features that represent significant barriers or crossing difficulties such as major roadways of bodies of water" *(Birk et al. 2010)*.

The BQI (segment level) is a function of the following variables:

1. Motor vehicle speed: this model used a categorical ranking of prevailing motor vehicle speeds
2. Motor vehicle volume: this model used a categorical ranking of average motor vehicle volume
3. Number of motor vehicle lanes: motor vehicle lanes were counted on each roadway
4. Bike lane drops: the number of time a bike lane drops within a segment of bikeway

5. Presence of a difficult transition: a difficult transition is defined as “Any point where cars and bikes are forced to interact mid-block through lane changes, left turns, etc. , is considered a difficult transition” *(Birk et al. 2010)*.

6. Width of a bicycle facility: the width (in feet) of a segment of bicycle facility

7. Number of “jogs” per mile: “A bicycle route jogs when a cyclist must turn off one street and onto another while a roadway continues straight (e.g. the bicycle route turns left or right and follows a different roadway for one or more blocks)” *(Birk et al. 2010)*.

8. Pavement quality: bikeway pavements were assigned a categorical rating of “good”, “fair”, or “poor”.

9. Intersection crossing quality: a categorical rating of 1 through 5. “Intersections were rated based on a number of criteria including: presence of a traffic control device, number of intersection legs, one-way or two-way directionality, the number of lanes, crossing width, presence and type of crosswalk, presence and type of median island, curb radii, on-street parking, sight distance, and street lighting. Intersections with bicycle crossing aids were rated higher” *(Birk et al. 2010)*.

10. Number of stop signs per mile: the number of stop signs per mile was included to account for their detrimental effect on the quality of a bicycle route, as “cycling is most energy intensive when moving from stationary to cruising speed” *(Birk et al. 2010)*.

The BQI introduces a number of variables that address connectivity and bicycle suitability at the route level, some of these variables include: number of times a bike lane drops within a segment, presence of a difficult transition, number of “jogs” (turns in bike route) per mile, and number of stop signs per mile.

The CZA introduces many variables that aim to measure accessibility and connectivity for the bicycle mode, some of these variables include: road and bicycle network density, permeability between zones, and connected node ratio.

2.1.19 Bicycle Level of Service (HCM BLOS), 2010

The Highway Capacity Manual (HCM) 2010 includes a multi-modal level of service (MMLOS) method for urban streets. The MMOLS framework takes into consideration the perspectives of motor vehicle drivers, pedestrians, bicycles and transit users (Transportation Research Board 2010) for different types of transportation facilities. The HCM 2010 integrates the effects of motor vehicles on pedestrians and bicyclists.

According to the HCM, BLOS *is* a performance measure used to describe the operational performance of transportation facilities and should reflect travelers’ perceptions, be useful to transportation agencies, and should be directly measured in the field *(Transportation Research Board 2010)*.

The LOS concept was first introduced by the 1965 Highway Capacity Manual (HCM) (Transportation Research Board 2010) to describe motorized traffic flows on road segments and intersections. The 2010 HCM defines three different concepts that somewhat overlap in meaning: quality of service, level of service, and service measures. *Quality of service* is how the traveler perceives the functioning of the roadway facility. (Table 2.1) The inputs for quality of service include travel surveys, complaints, and field observations. *Level of Service (LOS)* is the grading system used to describe certain thresholds of quality of service. According to the HCM, the LOS measurement is used to describe different transportation elements and service measures. *Elements* of a roadway include segments, points, facilities, corridors, areas, and systems. *Service measures* define LOS measures for different elements. Service measures should be able to interpret user's perceptions and be measureable in the field. LOS measurements are often developed by collecting information, such as geometric, motor vehicle performance and volume variables, and compare them to the surveys of facility users. Regression analysis, order probit models, and fuzzy clustering are common methods for developing/estimating LOS formulas/classification methods.

Motorized traffic LOS on road segments is defined by the density (motor vehicles per mile) and speed of traffic flow; LOS at intersections is defined by the average delay (seconds) experienced by a vehicle. LOS is rated on an A through F scale, with A being the best (free flow conditions) and F being the worst (demand exceeds capacity). While motorized traffic LOS is mostly based on motorized vehicles speed and delay considerations, for bicycles the 2010 Highway Capacity Manual Bicycle Level of Service (BLOS) has a score model that includes variables associated to riders' perception of LOS.

Table 2.1: Service Measures for different Elements from the HCM 2010

System Element	Motor Vehicles	Bicycles
• Freeways and Multi-lane Highways	• Density	• Comfort • Perceived exposure*
• Two-Lane-Highway	• Percent time following • Average Travel Speed • Percent free-flow speed	• Comfort • Perceived exposure**
• Urban Street Facilities and Segments	• Percent free-flow speed	• Comfort • Perceived exposure***
• Urban Street Intersections	• Control Delay	• None
• Off-street pedestrian and bicycle facilities	• none	• Number of times bicyclist meets other path users per minute • Delay from passing another bicycle or user • Presence of center line • Path width

* Variables include separation from traffic, motorized traffic volumes and speeds, heavy vehicle percentage, and pavement quality.
** Variables include separation from traffic, motorized traffic volumes and speeds, heavy vehicle percentage, on-highway parking and pavement quality.
*** Variables include separation from traffic, motorized traffic and volumes, heavy vehicle percentage, presence of parking, pavement quality. Intersections are included in the segment and include separation of traffic, cross street width.

BLOS is a perception of comfort and exposure. The BLOS is based on viewer ratings (on a six point scale) of video clips. Many of the videos of facilities and biking conditions may not compare well with Oregon facilities and biking conditions since they are from Florida. Bicycle speed is important but additional variables include traffic and geometric variables associated to both motorized and bicycle movements and infrastructure: separation from motorized traffic, motorized traffic volumes, traffic speeds, heavy-vehicle percentage, presence of parking, pavement quality. The HCM BLOS also includes considerations for bicycle flow characteristics and congestion. The HCM differentiates BLOS for off-street (Chapter 23) and on-street facilities; for on-street facilities the HCM has different methodologies for segments (Chapter 17) and intersections (Chapter 18) or for combining different facilities (segments and intersections). Table 2.1 describes a number of different system elements and compares the LOS service measurement used for motor vehicles and bicycles.

2.1.20 Simplified Bicycle Level of Service (BLOS), 2012

Using the same data that calibrated the HCM BLOS model, Ali et al. *(Ali et al. 2012)* developed a simplified model for measuring BLOS; to calibrate the model Ali et al. *(Ali et al. 2012)* used a cumulative logistic regression model instead of the standard linear regression model used for the HCM 2010 BLOS *(Ali et al. 2012)*. The data used to calibrate the HCM BLOS was collected as part of the NCHRP 3-70 Multimodal Level of Service for Urban Streets study *(Dowling et al. 2008)*. Ali et al. *(Ali et al.2008)* conducted a correlation analysis between LOS and the 13 variables outlined in the NCHRP report. The simplified BLOS keeps the four variables that have the highest correlation; these four variables are: the presence of a bicycle lane, the posted speed limit, the number of traffic lanes, and the number of unsignalized conflicts per mile. According to its authors the simplified BLOS is robust while using fewer variables that are easier to obtain or measure *(Ali et al. 2012)*.

The new ODOT Analysis Procedures Manual (APM)[2] will be implementing a simplified BLOS procedure to analyze the bicycle mode[3] in the multimodal analysis chapter. The simplified BLOS method provides a higher resolution BLOS assessment than the LTS method (discussed in following section), but requires less data than the full HCM BLOS analysis method. The intent of multiple methods in the APM is to enable planning tools at various stages of the planning process. For example, an LTS-based connectivity tool can help identify missing segments to reach all user groups whereas more detailed corridor and intersection BLOS/tools can follow-up by refining how best to implement a solution to the connectivity gap.

2.1.21 Level of Traffic Stress (LTS), 2012

In the recent literature, **level of stress** or **level of traffic stress (LTS)** primarily refers to a specific evaluation method developed by Mekuria et al. *(Mekuria et al. 2012)* in Mineta Transportation Institute project 11-19. Level of stress is not a new concept and previous work/methods such as the Bicycle Stress Level (BSL from 1994) and the Intersection Hazard Score (IHS from 1994) have utilized similar language.

LTS is primarily intended as a network assessment tool, rather than a segment or intersection evaluation tool. The LTS can be used to delineate islands of low-stress network connectivity and highlight disconnections and stressful links/nodes within a bicycle network.

The LTS related to motorized traffic is a function of the following variables:

1. Facility Type
2. Number of motor vehicle lanes
3. Bike lane and outside shoulder width (shoulder includes parking/gutter)
4. Speed limit
5. Bike lane blockage (frequency)
6. Presence of On-Street Parking

[2] http://www.oregon.gov/ODOT/TD/TP/Pages/APM.aspx
[3] Private correspondence with Peter L. Schuytema, P.E., Senior Transportation Analyst Transportation Planning Analysis Unit, ODOT

Table 2.2: Levels of Traffic Stress (LTS) ***(Mekuria, Furth, and Nixon 2012)***

LTS 1	Presenting little traffic stress and demanding little attention from cyclists, and attractive enough for a relaxing bike ride. Suitable for almost all cyclists, including children trained to safely cross intersections. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where cyclists ride alongside a parking lane, they have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
LTS 2	Presenting little traffic stress and therefore suitable for most adult cyclists but demanding more attention than might be expected from children. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where a bike lane lies between a through lane and a right-turn lane, it is configured to give cyclists unambiguous priority where cars cross the bike lane and to keep car speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.
LTS 3	More traffic stress than LTS 2, yet markedly less than the stress of integrating with multilane traffic, and therefore still suitable for many people currently riding bikes in American cities. Offering cyclists either an exclusive riding zone (lane) next to moderate-speed traffic or shared lanes on streets that are not multilane and have moderately low speed. Crossings may be longer or across higher-speed roads than allowed by LTS 2, but are still considered acceptably safe to most adult pedestrians.
LTS 4	A level of stress beyond LTS 3

LTS categorizes segments of a bicycle network based on a rating of traffic stress 1-4, “1” being the least stressful and “4” being the most stressful as seen in Table 2.2.

The new ODOT Analysis Procedures Manual (APM)[4] uses a LTS based procedure to analyze the bicycle mode[5] in the multimodal analysis chapter. The ODOT APM has added additional language for LTS 4, see Table 2.3. The draft ODOT APM added a LTS 5 category (to distinguish very stressful routes from “completely unacceptable” routes) but this LTS 5 category was deleted in the final published version of the APM.

[4] http://www.oregon.gov/ODOT/TD/TP/Pages/APM.aspx

[5] Private correspondence with Peter L. Schuytema, P.E., Senior Transportation Analyst Transportation Planning Analysis Unit, ODOT

Table 2.3: Additional Language for LTS - (Schuytema, P., 2014) Chapter 14, ODOT APM

LTS 4	Represents high stress and suitable for experienced and skilled cyclists. Traffic speeds are moderate to high and can be on roadways from two to over five lanes wide. Intersections can be complex, wide, and or high volume/speed that can be perceived as unsafe by adults and are difficult to cross. Typical locations include high-speed or multilane roadways with narrow or no bike lanes.

Mekuria et al. indicate that other factors such as crime, steep hills or pavement quality can be incorporated into the method by decreasing the rating of a link or intersection. They also indicate that low stress bicycle routes should be no longer than 25% of the shortest path using links with any type of stress level.

The LTS focus is on the suitability of different cycling environments as a function of different user groups' tolerance for traffic stress. Mekuria et al. suggest that LTS categories mesh well with the user groups theorized by Geller *(Geller 2006)* and validated by Dill and McNeil *(Dill and McNeil 2012)*. Geller grouped riders into the following four types:

1. **Strong and Fearless:** The smallest group (<1%) represents people who will travel by bicycle under any condition and on any roadway.

2. **Enthused and Confident:** The user group (~7%) already riding frequently in Portland. Advanced cyclists who travel on most roadways but enjoy the advantages of bicycle infrastructure.

3. **Interested but Concerned**: The user group (~60%) that is interested in cycling but has safety concerns. They would ride if roadway conditions (i.e. bicycle infrastructure) were perceived to be safe enough.

4. **No Way, No How:** The user group (~33%) that will not cycle, either because of disability, age, or complete lack of interest.

Mekuria et al. suggest that: LTS 1 is adequate for children; LTS 2 are the Dutch standards that are suitable for the *Interested but Concerned* segment; LTS 3 describes the *Enthused and Confident*, segment that feels comfortable riding on bike lanes along arterials; and LTS 4 describes the *Strong and Fearless* segment.

2.1.22 Bicycle Level of Service (Jensen's BLOS at Intersections), 2013

Jensen developed another evaluation method in 2013 *(Jensen 2013)* specifically for intersections, as opposed to segments (already reviewed Jensen's BLOS). The method was developed as part of a study sponsored by the Danish Road Directorate to "objectively quantify pedestrian and cyclist stated satisfaction with roundabouts, signalized and non-signalized intersections, mid-block crossings, and pedestrian bridges and tunnels" *(Jensen 2013)*. Only the bicycle methods are considered herein. As in the segment method, the BLOS is based on viewer ratings (on a six point scale) of video clips. The BLOS was modeled using a cumulative logit regression, with the ratings and intersection variables (e.g. length of crossing, traffic volume, etc.) calibrating the model coefficients. The following variables were measured for the different crossing types:

1. Signalized Intersection

   a. Bicycle facility type before stop line

   b. Bicycle facility type within intersection

   c. Waiting time

   d. Urban or rural zone

   e. Crossing distance

   f. Motor vehicle volume

2. Roundabout

   a. Bicycle facility before and at roundabout

   b. Motor vehicle volume

   c. Crossing distance

   d. Circulating lane(s) (e.g. single-lane or multi-lane)

3. Non-signalized crossing

   a. Sidewalk across minor approach presence

   b. Right-of-way condition (yield sign or stop sign)

   c. Motor vehicle speed

   d. Motor vehicle volume

2.2 BLOS LITERATURE SUMMARY AND DISCUSSION

All the BLOS and related methods described in the previous section are summarized in Table 2.4; a review of this table indicates that the scope of most methods is limited to *Segments* and/or *Intersections*. The HCM BLOS can be extended to routes (groups of intersections and segments) using a weighted average BLOS but without taking into account the bicycle network characteristics or properties.

Most methods are applicable or designed for urban areas. Two methods were designed specifically for rural facilities: the Rural Bicycle Compatibility Index (RBCI) and the Compatibility of Roads for Cyclists (CRC). Though there are other methods such as ODOT's LTS and the Bicycle Suitability Score (BSS) that can be used in rural settings. ODOT's LTS methodology has a rural application section that utilized daily volume ranges and shoulder widths.

There are just two general methods that focus on networks and/or areas: the Bicycle Quality Index (BQI) and Cycle Zone Analysis (CZA), and the Level of Traffic Stress (LTS) method. Networks are useful to evaluate bicycle network properties (e.g. connectivity, density) and useful to evaluate routes, i.e. origin destination paths. This is critical to identify whether all user groups can reach key destinations with a reasonable level of comfort and what network link enhancements can provide the most benefit to the most users. Zones or areas are used to cluster intersections and segments within a specific boundary, the determination of "homogeneous" zones can be used to highlight gaps or insufficiencies within a bicycle network.

Table 2.4: Summary of Methods and their Scope

Method Number	Name	Acronym	Scope	Reference	Reference Year
1	Bicycle Safety Index Rating	BSIR	Segment	*(Davis 1987)*	1987
2	Bicycle Stress Level	BSL	Segment	*(Sorton and Walsh 1994)*	1994
3	Road Condition Index	RCI	Segment	Epperson *(Epperson 1994)*	1994
4	Interaction Hazard Score	IHS	Intersection	*(Landis 1994)*	1994
5	Bicycle Suitability Rating	BSR	Segment	*(Davis 1995)*	1995
6	Bicycle Level-of-Service	BLOS	Segment	*(Botma 1995)*	1995
7	Bicycle Level-of-Service	BLOS	Segment	*(Dixon 1996)*	1996
8	Bicycle Suitability Score	BSS	Segment	*(Turner et al. 1997)*	1997
9	Bicycle Compatibility Index	BCI	Segment	*(Harkey et al. 1998)*	1998
10	Bicycle Suitability Assessment	BSA	Segment	*(Emery and Crump 2003)*	2003
11	Rural Bicycle Compatibility Index	RBCI	Rural Segment	*(Jones and Carlson 2003)*	2003
12	Compatibility of Roads for Cyclists	CRC	Rural Segments	*(Noël et al. 2003)*	2003
13	Bicycle Intersection Safety Index	BISI	Intersection	*(Carter et al. 2007)*	2007
14	Bicycle Level-of-Service	BLOS	Segment	*(Zolnik and Cromley 2007)*	2007
15	Bicycle Level-of-Service	BLOS	Segment	*(Jensen 2007)*	2007

16	Bicycle Level-of-Service	BLOS	Segment	*(Petritsch et al. 2008)*	2007
17	Bicycle Environmental Quality Index	BEQI	Segment, Intersection	*(San Francisco Department of Public Health 2009)*	2009
18	Bicycle Quality Index and Cycle Zone Analysis	BQI & CZA	Segment, Network, Zone	*(Birk et al. 2010)*	2010
19	Bicycle Level-of-Service	BLOS	Segment & Intersection	*(Transportation Research Board 2010)*	2010
20	Simplified Bicycle Level of Service	BLOS	Segment	*(Ali et al. 2012)*	2012
21	Level of Traffic Stress	LTS	Intersection, Segment, Network, Zone	*(Mekuria et al. 2012)*	2012
22	Bicycle Level-of-Service at Intersections	BLOS	Intersection	*(Jensen 2013)*	2013

The result of grouping almost 60 variables or attributes used by the different BLOS methods can be seen in Table 2.5. The last column measures the "acceptance" of the variable by indicating how many and what method utilizes the variables. Bikeway design variables are clearly essential; however most methods also include variables associated with motorized traffic volume and speed or motorized traffic facilities geometric design.

Most of the variables can be directly observed or directly measured in the field as the 2010 HCM specify. Most general nuisance/hazards/environment (bikeway or built environment) can be observed in the field whereas most geometric and traffic variables can be measured (speeds) or counted (traffic volumes) in the field. The group of network specific variables is the only exception. For example, some of the network variables such as bicycle network density or average connected node ratio are best measured using software (e.g. a GIS program and using network GIS files).

GIS systems can be useful for implementing BLOS methods by storing the necessary link/intersection data, implementing BLOS formulas, and mapping the results at the segment, corridor, or urban area level *(Lowry and Callister 2012)*. As mentioned earlier, GIS systems are necessary to effectively implement network or area based methods such as CZA or LTS.

Smartphone data can provide detailed disaggregated route data and some user demographic information. This type of information cannot be incorporated directly into any of the methods that are used to analyze segments or intersections. In addition, user attributes are key to forecasting who will benefit from improvements and to link to travel model O-D tables. Disaggregated data can also be used to study route choices by user groups. Smartphone data can be more useful for methods that are used to analyze bicycle networks (e.g. CZA and LTS methods) and for methods that can aggregate users into user groups (e.g. the LTS method).

However, GIS systems do have the limitation of not being routable without large datasets of network parameters indicating the connectivity of links. These sorts of datasets are not consistently available in all areas. Some options exist for generating routes in order to evaluate some aspect of a bicycle network, including Google Maps and the Tri-Met developed Open Trip Planner[6] as well as travel demand modeling software EMME and VISUM (ODOT has licenses for both). A combination of GIS and these routable software systems will provide the full functionality necessary in evaluating BLOS at the intersection, segment, and network levels.

Table 2.5: BLOS Variables by Category

Bikeway Geometric Design	Facility Type	Categorical	RCI[3], BLOS[7], BCI[9], BISI[13], CZA[18], BLOS[19], BLOS[20], LTS[21], BLOS[22]
	Width of Bicycle Facility	Number (feet)	IHS[4], BLOS[6], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BEQI[17], BQI[18], BLOS[19], LTS[21]
	Topographic Grade	Number (% grade)	RCI[3], BSR[5], BSA[10], BEQI[17], CZA[18]
Bikeway Environment	Width of MV Buffer (proximity to edge of moving traffic lane)	Number (feet)	BLOS[15], LTS[19]
	Bicycle marking presence	Categorical	BSA[10], BEQI[17]
	Presence of bicycle signage	Categorical	BEQI[17]
	Presence of trees	Categorical	BEQI[17]
	Presence of bicycle scale lighting	Categorical	BEQI[17]
	Width of Shoulder	Number (feet)	BSS[8], BCI[9], BSA[10], RBCI[11], BLOS[19], LTS[21]
	Presence of Sidewalks	Categorical	BSA[10], BLOS[15]
Roadway Geometric Design	Number of Vehicle Lanes	Number (count)	BSIR[1], RCI[3], IHS[4], BSR[5], BSA[10], BSA[10], BLOS[15], BLOS[16], BEQI[17], BLOS[19], BLOS[20], LTS[21]
	Width of Outside	Number (feet)	BSIR[1],BSL[2], RCI[3],

[6] Tri-Met Open Trip Planner: http://trimet.org/howtoride/maptripplanner.htm

	Lane		IHS[4], BSR[5], BLOS[7], BSS[8], BCI[9], BSA[10], RBCI[11], BLOS[15], BLOS[16], BLOS[19]
	Turning Lane Configuration	Categorical	BCI[9], BSA[10], BEQI[17]
	Physical Median	Categorical	RCI[3], BLOS[7], BSA[10]
	Frequent Curves	Categorical	BSA[10]
Bicycling Nuisance/Hazard	Presence of On-Street Parking	Categorical (2)	RCI[3], BSR[5], BLOS[7], BCI[9], BSA[10], BISI[13], BLOS[15], BEQI[17], BLOS[19], LTS[21]
	Occupancy of On-Street Parking	Number (%)	BCI[9],
	Conflicting Transit Stop Presence	Categorical	BLOS[15],
	Presence of a Curb	Categorical (2)	BSA[10], BLOS[19]
	Storm Drain Grates	Categorical (2)	RCI[3], BSR[5], BSA[10],
	Roadside Hazard Presence (Sand, gravel, vegetation, ditches)	Categorical	CRC[12]
	Restricted Sight Distance	Categorical	BSR[5], BLOS[7], BSA[10], BEQI[17],
	Access point density	Number (# access points per mile)	IHS[4], RBCI[11], CRC[12], BLOS[16], BEQI[17], BLOS[20]
	Numerous Driveways	Categorical	BSA[10]
	Rail Crossings	Number (count)	RCI[3], BSR[5], BSA[10]
	Bike Lane Drop	Number (# times within segment)	BQI[18],
	Difficult Transition	Number per Segment	BQI[18],
Bikeway Condition	Pavement Condition	Location, Picture, Description	BSIR[1], RCI[3], IHS[4], BSR[5], BLOS[7], BSS[8], BSA[10], CRC[12], BLOS[16], BEQI[17], BLOS[19]
Roadway Traffic	Vehicle Traffic Volume	Number (veh/day)	BSIR[1],BSL[2], RCI[3], IHS[4], BSR[5], BSS[8], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BLOS[16], BEQI[17], BQI[18], BLOS[19], BLOS[22]
	Right Turning	Number (veh per hr or	BCI[9]

	Vehicle Volume	day)	
	Vehicle Speed	Number (mph)	BSIR[1],BSL[2], RCI[3], IHS[4], BSR[5], BLOS[7], BSS[8], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BLOS[16], BQI[18], BLOS[19], BLOS[20], LTS[21]
	Percentage of Heavy Vehicles	Number (%)	IHS[4],BCI[9], RBCI[11], CRC[12], BLOS[16], BEQI[17], BLOS[18]
	Motor Vehicle LOS	Categorical (A-F)	BLOS[7]
	Bicycle Lane Blockage	Categorical	LTS[21]
Bikeway Traffic	Average Speed/Acceleration	Number(ft/s or ft/s^2)	BLOS[6], BLOS[19]
	Bicycle Volumes	Number (bikes/hr or day)	BLOS[6], BLOS[19]
	Pedestrian Volume (for multi-use paths)	Number (bikes/hr or day)	BLOS[6], BLOS[19]
Intersection Specific	"No Turn on Red" sign	Categorical	BEQI[17], BLOS[22]
	Intersection Type	Categorical	BISI[13], BLOS[22]
	Intersection Quality	Categorical	BSA[10], CZA[18]
	Crossing Distance	Number (feet)	BISI[13], BLOS[22]
	Number of lanes crossed for cyclist left turn		BISI[13]
	Number of lanes crossed for cyclist right turn		BISI[13]
	Signal Delay	Number (seconds)	BLOS[22]
Built Environment	Activity Density	Number (Pop. + Employment per sq. mile)	IHS[4]
	Adjacent Land Use Type	Categorical	BSR[5], BCI[9], BSA[10], BLOS[15], BEQI[17],
	Multi-modal or TOD Proximity	Categorical	BLOS[7]
	Bicycle parking presence	Categorical	BEQI[17]
Network	Connectivity	Number (connected node ratio)	BEQI[17], CZA[18]
	Presence of Parallel Facility	Categorical	BLOS[7]
	Intersection Density	Number (Intersections	RBCI[11]

		per sq. mile)	
	Road Network Density	Number (Linear Feet per sq. mile)	CZA[18]
	Bicycle Network Density	Number(Linear Feet per sq. mile)	CZA[18]
	Permeability/Barrier	Number ("score" per feet-boundary)	BLOS[7], CZA[18]
	Stops	Number (# stop signs per mile)	BQI[18]
	Route Simplicity	Number (Turns per mile)	BQI[18]
	Detour	% over shortest path distance	LTS[21]

2.2.1 Variable Groups

The variables or data attributes used by the different BLOS methods can be grouped into several categories such as:

- - Bikeway geometric design (e.g. width, slope)
- - Bikeway environment (e.g. shoulders, proximity to traffic, presence of trees)
- - Roadway geometric design (e.g. number of lanes)
- - Bicycle nuisances/hazards (e.g. drain grates, on-street parking, restricted sight distance)
- - Bikeway Condition (e.g. pavement condition)
- - Roadway Traffic (e.g. motorized volume/speed)
- - Bikeway Traffic (e.g. bicycle volume/speed)
- - Intersection specific (e.g. signal delay)
- - Built environment (e.g. adjacent land use)
- - Network specific (e.g. bicycle network density)

The result of grouping almost 60 variables or attributes into these categories can be seen in Table 2.5. The last column measures the "acceptance" of the variable by indicating how many and what method utilizes the variables. Bikeway design variables are clearly essential; however most methods also include variables associated with motorized traffic volume and speed or motorized traffic facilities geometric design.

Most of the variables can be directly observed or directly measured in the field as the 2010 HCM specify. Most general nuisance/hazards/environment (bikeway or built environment) can be observed in the field whereas most geometric and traffic variables can be measured (speeds) or counted (traffic volumes) in the field. The group of network specific variables is the only exception. For example, some of the network variables such as bicycle network density or average connected node ratio are best measured using software (e.g. a GIS program and using network GIS files).

GIS systems can be useful for implementing BLOS methods by storing the necessary link/intersection data, implementing BLOS formulas, and mapping the results at the segment, corridor, or urban area level *(Lowry and Callister 2012).* As mentioned earlier, GIS systems are necessary to effectively implement network or area based methods such as CZA or LTS.

Smartphone data can provide detailed route data and some user demographic information. This type of information cannot be incorporated directly into any of the methods that are used to analyze segments or intersections. Smartphone data can be more useful for methods that are used to analyze bicycle networks (e.g. CZA and LTS methods) and for methods that can aggregate users into user groups (e.g. the LTS method).

However, GIS systems do have the limitation of not being routable without large datasets of network parameters indicating the connectivity of links. These sorts of datasets are not consistently available in all areas. Some options exist for generating routes in order to evaluate some aspect of a bicycle network, including Google Maps and the Tri-Met developed Open Trip Planner[7]. A combination of GIS and these routable software systems will provide the full functionality necessary in evaluating BLOS at the intersection, segment, and network levels.

Table 2.6: BLOS Variables by Category

Category	Parameter	Data Type	Methods that Utilize Parameter (see Table 4 for a reference)
Bikeway Geometric Design	Facility Type	Categorical	RCI[3], BLOS[7], BCI[9], BISI[13], CZA[18], BLOS[19], BLOS[20], LTS[21], BLOS[22]
	Width of Bicycle Facility	Number (feet)	IHS[4], BLOS[6], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BEQI[17], BQI[18], BLOS[19], LTS[21]
	Topographic Grade	Number (% grade)	RCI[3], BSR[5], BSA[10], BEQI[17], CZA[18]
Bikeway Environment	Width of MV Buffer (proximity to edge of moving traffic lane)	Number (feet)	BLOS[15], LTS[19]

[7] Tri-Met Open Trip Planner: http://trimet.org/howtoride/maptripplanner.htm

	Bicycle marking presence	Categorical	BSA[10], BEQI[17]
	Presence of bicycle signage	Categorical	BEQI[17]
	Presence of trees	Categorical	BEQI[17]
	Presence of bicycle scale lighting	Categorical	BEQI[17]
	Width of Shoulder	Number (feet)	BSS[8], BCI[9], BSA[10], RBCI[11], BLOS[19], LTS[21]
	Presence of Sidewalks	Categorical	BSA[10], BLOS[15]
Roadway Geometric Design	Number of Vehicle Lanes	Number (count)	BSIR[1], RCI[3], IHS[4], BSR[5], BSA[10], BSA[10], BLOS[15], BLOS[16], BEQI[17], BLOS[19], BLOS[20], LTS[21]
	Width of Outside Lane	Number (feet)	BSIR[1],BSL[2], RCI[3], IHS[4], BSR[5], BLOS[7], BSS[8], BCI[9], BSA[10], RBCI[11], BLOS[15], BLOS[16], BLOS[19]
	Turning Lane Configuration	Categorical	BCI[9], BSA[10], BEQI[17]
	Physical Median	Categorical	RCI[3], BLOS[7], BSA[10]
	Frequent Curves	Categorical	BSA[10]
Bicycling Nuisance/Hazard	Presence of On-Street Parking	Categorical (2)	RCI[3], BSR[5], BLOS[7], BCI[9], BSA[10], BISI[13], BLOS[15], BEQI[17], BLOS[19], LTS[21]
	Occupancy of On-Street Parking	Number (%)	BCI[9],
	Conflicting Transit Stop Presence	Categorical	BLOS[15],
	Presence of a Curb	Categorical (2)	BSA[10], BLOS[19]
	Storm Drain Grates	Categorical (2)	RCI[3], BSR[5], BSA[10],
	Roadside Hazard Presence (Sand, gravel, vegetation, ditches)	Categorical	CRC[12]
	Restricted Sight Distance	Categorical	BSR[5], BLOS[7], BSA[10], BEQI[17],
	Access point density	Number (# access points per mile)	IHS[4], RBCI[11], CRC[12], BLOS[16], BEQI[17], BLOS[20]

	Numerous Driveways	Categorical	BSA[10]
	Rail Crossings	Number (count)	RCI[3], BSR[5], BSA[10]
	Bike Lane Drop	Number (# times within segment)	BQI[18],
	Difficult Transition	Number per Segment	BQI[18],
Bikeway Condition	Pavement Condition	Location, Picture, Description	BSIR[1], RCI[3], IHS[4], BSR[5], BLOS[7], BSS[8], BSA[10], CRC[12], BLOS[16], BEQI[17], BLOS[19]
Roadway Traffic	Vehicle Traffic Volume	Number (veh/day)	BSIR[1],BSL[2], RCI[3], IHS[4], BSR[5], BSS[8], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BLOS[16], BEQI[17], BQI[18], BLOS[19], BLOS[22]
	Right Turning Vehicle Volume	Number (veh per hr or day)	BCI[9]
	Vehicle Speed	Number (mph)	BSIR[1],BSL[2], RCI[3], IHS[4], BSR[5], BLOS[7], BSS[8], BCI[9], BSA[10], RBCI[11], CRC[12], BLOS[15], BLOS[16], BQI[18], BLOS[19], BLOS[20], LTS[21]
	Percentage of Heavy Vehicles	Number (%)	IHS[4],BCI[9], RBCI[11], CRC[12], BLOS[16], BEQI[17], BLOS[18]
	Motor Vehicle LOS	Categorical (A-F)	BLOS[7]
	Bicycle Lane Blockage	Categorical	LTS[21]
Bikeway Traffic	Average Speed/Acceleration	Number(ft/s or ft/s^2)	BLOS[6], BLOS[19]
	Bicycle Volumes	Number (bikes/hr or day)	BLOS[6], BLOS[19]
	Pedestrian Volume (for multi-use paths)	Number (bikes/hr or day)	BLOS[6], BLOS[19]
Intersection Specific	"No Turn on Red" sign	Categorical	BEQI[17], BLOS[22]
	Intersection Type	Categorical	BISI[13], BLOS[22]
	Intersection Quality	Categorical	BSA[10], CZA[18]
	Crossing Distance	Number (feet)	BISI[13], BLOS[22]
	Number of lanes crossed for cyclist		BISI[13]

	left turn		
	Number of lanes crossed for cyclist right turn		BISI[13]
	Signal Delay	Number (seconds)	BLOS[22]
Built Environment	Activity Density	Number (Pop. + Employment per sq. mile)	IHS[4]
	Adjacent Land Use Type	Categorical	BSR[5], BCI[9], BSA[10], BLOS[15], BEQI[17],
	Multi-modal or TOD Proximity	Categorical	BLOS[7]
	Bicycle parking presence	Categorical	BEQI[17]
Network	Connectivity	Number (connected node ratio)	BEQI[17], CZA[18]
	Presence of Parallel Facility	Categorical	BLOS[7]
	Intersection Density	Number (Intersections per sq. mile)	RBCI[11]
	Road Network Density	Number (Linear Feet per sq. mile)	CZA[18]
	Bicycle Network Density	Number(Linear Feet per sq. mile)	CZA[18]
	Permeability/Barrier	Number ("score" per feet-boundary)	BLOS[7], CZA[18]
	Stops	Number (# stop signs per mile)	BQI[18]
	Route Simplicity	Number (Turns per mile)	BQI[18]
	Detour	% over shortest path distance	LTS[21]

A review of the LOS and stress levels estimation literature indicates that terminology is not consistent and sometimes even confusing. To establish a consistent terminology for this and future project tasks, the following definitions are proposed.

2.3 TERMINOLOGY SUMMARY

This section reviews some commonly used terms use to measure the quality of bicycling and/or bicycle facilities as a mode or in relation to accessibility or user groups. There are many overlaps between terms and for the sake of conceptual clarity, this report adopts the following conceptual table (see Table 2.8); in bold and in the diagonal the feature or scope that uniquely characterizes the term.

These definitions are employed in final Section to discuss data gaps and applications that can be addressed utilizing or integrating smartphone data. Next section describes and summarizes existing bicycle and infrastructure related smartphone applications.

2.3.1 BLOS Methods

To define Bicycle Level of Service (BLOS) we essentially follow the 2010 HCM guidelines: BLOS is a performance measure used to describe the performance (comfort, safety, operation, etc.) of bicycle facilities and should reflect travelers' perceptions, be useful to transportation agencies, and be directly measured in the field.

Some BLOS are complex and data intensive. Most BLOS are simple, user-friendly, with readily understandable calculations or scores, and not data intensive. An example of the former includes the 2010 HCM BLOS; examples of the latter include the Bicycle Suitability Score (BSS), Bicycle Compatibility Index (BCI) and the Bicycle Suitability Assessment (BSA).

In this report **BLOS** is defined as any bicycle performance measure that *can be computed* (based on a formula or score) *utilizing data/variables that are measured or observed in the field* (geometric, environmental, nuisance, or traffic variables).

2.3.2 Network BLOS

We define **network BLOS** as a performance measure (or weighted set of performance measures) used to describe the performance of bicycle facilities at the network level. Network BLOS should also reflect bicyclists' perceptions but they *are measured not in the field but using network models* (i.e. in networks defined by sets of nodes and links) and are usually best calculated using software packages (GIS systems or network algorithms).

Some bicycle network properties like connectivity may be used with different purposes. Connectivity can be used to reflect the number of large city blocks or dead end streets that increase travel distance *(Cervero and Duncan 2003)* or connectivity may be associated with safety when a bicycle route has a single connection that is beyond the user's ability or comfort level *(Mekuria et al. 2012)*.

Network BLOS methods are particularly useful in areas with underdeveloped bicycle networks, where basic connectivity is of greater concern than facility quality. It is also useful in area where bicycle networks are more developed, but adequate data is not available to employ standard BLOS methods.

2.3.3 Level of Traffic Stress (LTS)

In the recent literature, level of traffic stress or (LTS) primarily refers to a specific evaluation method developed by Mekuria et al. *(Mekuria et al. 2012).* Level of stress is not a new concept, and previous work/methods have utilized similar language (e.g. the Bicycle Stress Level or BSL from 1994 is based on safety levels and physical/mental effort as a function of age).

Unlike BLOS or network BLOS methods, a LTS measure serves as a proxy for measuring the desirability of a bicycle facility for segments of the population with different levels of age, experience or skill. In this report **LTS** is defined as a performance measure that takes into account not only traffic/geometric characteristics of the riding environment but *also the suitability of the environment for different user groups within the population*. LTS can be used to delineate islands of low-stress network connectivity, highlighting disconnections and especially stressful links within a bicycle network.

2.3.4 Bikeability

Another term that is commonly used in the bicycle literature is "bikeability". For example, McNeil *(McNeil 2011)* proposes a methodology that assigns points to various destination types, such as grocery stores or restaurants, and calculates a score out of one hundred for a given location by totaling up the points for destinations within a twenty minute bike ride. The method is similar to the popular Walk Score®, which calculates a score out of one hundred for an input address based on the number of destinations within walking distance *(Walk Score 2014)*.

The Bikeability Checklist *(Pedestrian and Bicyle Information Center 2002)*, developed by the Pedestrian and Bicycle Information Center (PBIC) at the University of North Carolina, is a simple form to be filled out by any citizen to assess the bikeability of their community. The user is asked to take a bike trip to one of their regular destinations and answer a series of questions about the comfort and convenience of their experience.

Unlike BLOS and LTS measures, in this report the definition of **bikeability** is a macro-level assessment of a network of bicycle facilities in terms of the *accessibility to important destinations*.

2.3.5 Bicycle Friendliness

Some bicyclist advocacy groups have developed the concept of "bicycle friendliness". The most well-known assessment of bicycle friendliness is conducted by the League of American Bicyclists (LAB). Cities or municipalities can submit a paid application biannually to the LAB for potential recognition as a "bicycle friendly community" at either the platinum, gold, silver, or bronze designation; with platinum being the highest designation. The LAB evaluation is based on assessment of the municipality with respect to five categories: engineering, education, encouragement, enforcement, and evaluation. Oregon has ten bicycle friendly communities, as labelled in Table 2.7.

LAB also has a state level assessment based on five categories: legislation, policies, and programs; infrastructure; education; enforcement; and evaluation. Instead of an application process, LAB assesses every state in the country on an annual basis and ranks them on their statewide bicycle friendliness. Oregon was ranked number three on the 2013 ranking list; with Washington and Colorado being numbers one and two, respectively *(League of American Bicyclists 2013a)*. LAB also has recently started evaluating bicycle friendly businesses and universities (also noted in Table 2.7). Other national and state organizations evaluate bicycle friendliness at various scales. Oregon's Bicycle Transportation Alliance (BTA) developed the

Bike Friendly Report Card to compare the bicycle friendliness of cities throughout Oregon *(Bicycle Transportation Alliance 2014).*

Table 2.7: Oregon's bicycle friendly designations (as of 2013) ***(League of American Bicyclists 2013b)***

Bicycle Friendly Designation:	Platinum	Gold	Silver	Bronze
Communities (i.e. municipalities):	• Portland	• Ashland • Corvallis • Eugene	• Bend • Sisters	• Albany • Beaverton • Gresham • Salem
Universities		• Portland State University	• Oregon State University • University of Oregon	
Businesses	• Alta Planning + Design • Bike Gallery	• King Cycle Group • Oregon Health & Science University • Sera Architects	• BicyclingHub.com • Frans Pauwels Memorial Community Bicycle Center • Integral Consulting Inc. • LifeCycle Adventures • Nelson Nygaard Consulting Associates – Portland • Standing Stone Brewing Co.	• Elliott Associates, Inc. • Galois • Jesuit Volunteer Corps Northwest • Mill Inn • Mountain Rose Herbs • OMRI (Organic Materials Review Institute) • PECI • Regence • Substance • Sunnyside Sports • The Standard • Travel Portland • Unico Properties

Table 2.8 : Overview of Terminology and Keywords (unique feature underlined)

Term→ Feature/Scope ↓	BLOS	Network BLOS	Level of Stress	Bikeability	Bicycle Friendliness
Segment/Intersection	✓̲		✓	✓	
Network PMs		✓̲	✓	✓	
User Group			✓̲		
Accessibility				✓̲	✓
Community & Government					✓̲

In this report, the definition of **bicycle friendliness** is a macro-level assessment *at the community and government level*. Friendliness is related to the degree of acceptance of cycling within the community and with the adoptions of programs, laws, and policies that protect and promote cycling.

3.0 REVIEW OF SMARTPHONE CROWDSOURCING APPLICATIONS

Crowdsourcing is defined in this report as the acquisition of information or input related to bicycling or its infrastructure by enlisting the participation of users/cyclists. The word crowdsourcing was barely used before 2006[8] and the rapid increase in its usage is linked to the growth of smartphones that can easily collect and transmit user data. There are numerous definitions of crowdsourcing[9] but this reports restricts crowdsourcing to smartphone applications (or apps) related to bicycling and transportation infrastructure. The review is not exhaustive since there are too many applications and many keep appearing, however, the review aims to cover the main applications (and their features) that have been developed up to date.

Although the boundaries between purposes are blurred, we identify four types of applications by type of purpose:

1. Transportation planning
2. Infrastructure maintenance or feedback
3. Recreational or fitness
4. Mapping and general apps

3.1 TRANSPORTATION PLANNING

The first application designed to collect bicycle data for planning purposes was CycleTracks. The CycleTracks app was developed by the San Francisco County Transportation Authority (SFCTA) and partially funded by a Caltrans planning grant *(San Francicso County Transportation Authority 2013)*. Its purpose is to estimate cycling demand on various bicycle facilities in San Francisco and is now used as source data for the SFCTA's travel demand model SF-CHAMP *(Zorn et al. 2011)*.

CycleTracks was first deployed in San Francisco, California in November 2009. Because CycleTracks code is open source, the posterior planning applications (e.g. Austin, Atlanta) were based on it or borrowed significantly from the original app.

3.1.1 San Francisco, CA – CycleTracks (2009)

CycleTracks uses the smartphone Global Positioning System (GPS) sensor to track user's trajectory. It can also provide some (optional) user demographic information; the demographic

[8] https://books.google.com/ngrams/graph?content=crowdsourcing&case_insensitive=on&year_start=1998&year_end=2008&corpus=15&smoothing=0&share=&direct_url=t4%3B%2Ccrowdsourcing%3B%2Cc0%3B%2Cs0%3B%3Bcrowdsourcing%3B%2Cc0%3B%3BCrowdsourcing%3B%2Cc0

[9] http://en.wikipedia.org/wiki/Crowdsourcing

information is collected to study self-selection and overrepresentation of some user groups. The application is available for download free of charge on the iTunes app store or the Android Play app store.

The development team had several critical criteria to guide the application development *(Schwartz and Hood 2011)*:

1. It must be free and quick to download and install
2. It must be as easy to use as possible, with minimum tapping/clicking necessary to get started, so even causal cyclists can use it
3. It must upload every track data immediately to [SFCTA's] central database using the phone's built-in data plan, so the user doesn't have to manually intervene, sync, or upload anything
4. It must not run down the user's battery
5. It needs a catchy name

The application records GPS coordinates which can later be converted to "GPS Traces" to attach to road and bicycle networks. Trip purpose is recorded at the end of each trip via a category selector. The following trip purposes are given as options:

1. Commute
2. School
3. Work-Related
4. Exercise
5. Social
6. Shopping
7. Errand
8. Other

If a trip purpose is considered an "Other", the user can enter that trip purpose into the comments field associated with each trip. The comments field is optionally filled in for each trip, and can supplement SFCTA's information about a route or trip. Users can then view their trip on the provided Google Maps application programming interface (API)[10]. Users also have the option of

[10] Google Maps API: https://developers.google.com/maps/

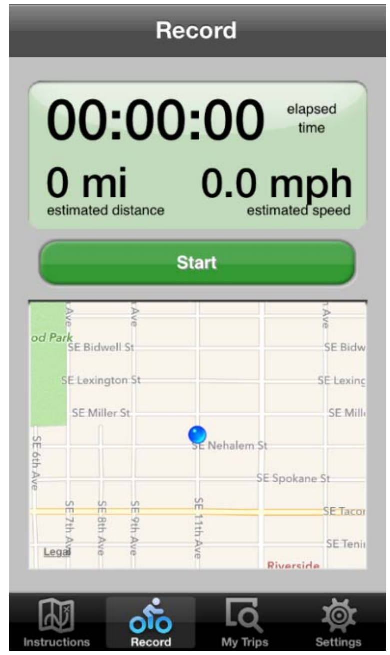
inputting demographic information within the "Settings" sub-menu; this only has to be done once. These optional additional information fields are:

- Age
- E-mail address
- Gender
- Home location ZIP code
- Work location ZIP code
- School location ZIP code
- Cycling frequency, with the following options:
    - Less than once a month
    - Several times per month
    - Several times per week
    - Daily

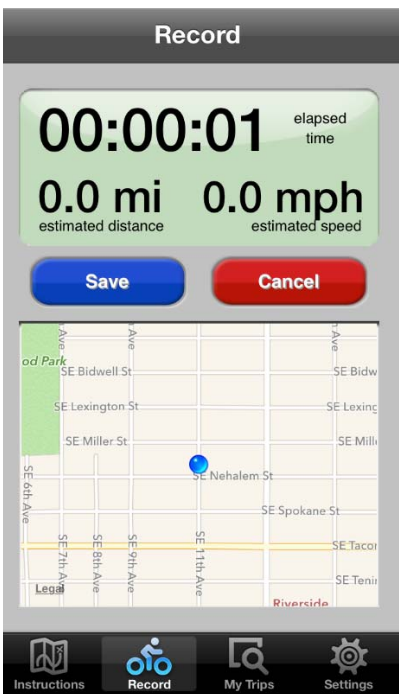
The basic application functionality is illustrated in Figure 3.1. More information about the application functionality can be found on CycleTracks' website *(San Francicso County Transportation Authority 2013)* or a 2011 Transportation Research Board (TRB) paper *(Schwartz and Hood 2011)*.

1. The application is opened

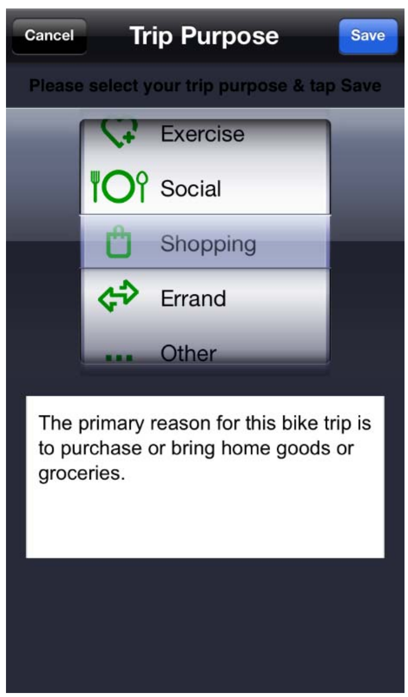
2. The user can optionally enter in demographic information and cycling frequency



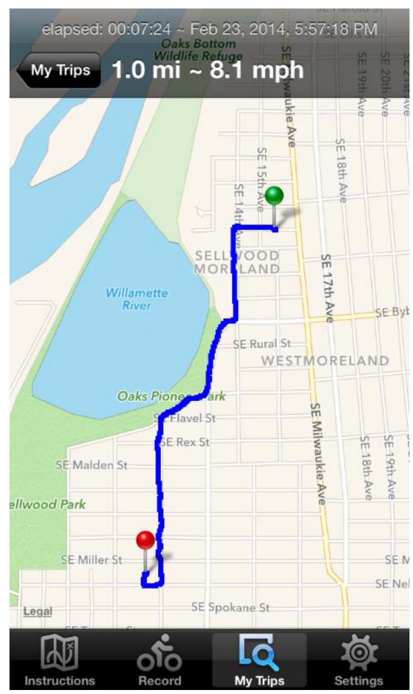
3. The user presses “Start” to begin recording a trip. GPS coordinates are now being recorded.



4. When the user arrives at their destination, the trip can be recorded by pressing “Save”.



5. The trip purpose is then entered, and the trip is then transferred to the server.



6. The user then can review their trip on the Google Maps API.

Figure 3.1: CycleTracks User Interface and Functionality (iOS version shown)

GPS communications are battery intensive, so consideration needs to be given to the user's phone battery life. CycleTracks addresses this with additional notification measures: the application "makes a 'bicycle bell' noise and vibrates after an initial 15 minutes of GPS data collection and every five minutes thereafter" *(Schwartz and Hood 2011)*. CycleTracks also shuts down when the user's phone battery has less than 10% charge left.

3.1.2 CycleTracks direct Ports

The applications discussed in this section made no significant functional changes to the CycleTracks app besides the name and in some cases the server used to store the data.

3.1.2.1 AggieTrack

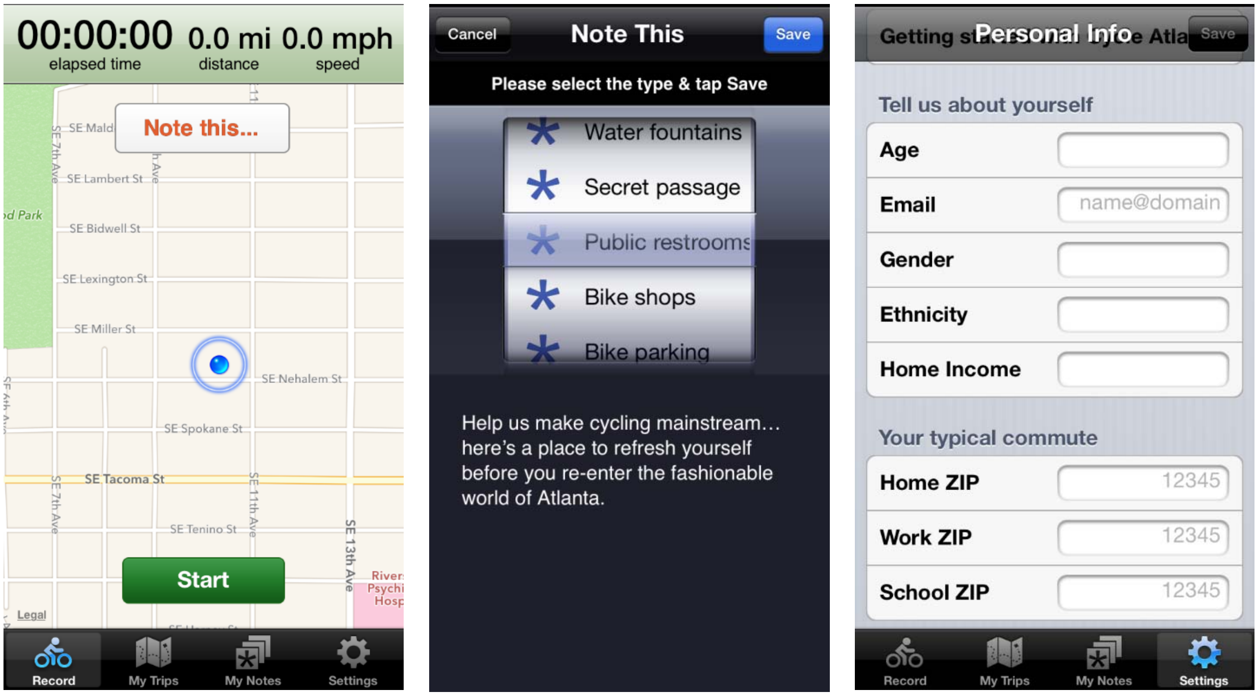
AggieTrack is used by Texas A&M University to track the travel patterns of members of the university community. The user inputs the mode of their transportation (in addition to the purpose of the trip) at the end of the trip. User info is also customized to members of the university community. AggieTrack asks for user "classification" from among the options of faculty, staff, freshman, sophomore, junior, senior, graduate, and post-doc. It also asks if the user lives on campus (yes/no) and whether they own a car (yes/no). Finally, it also asks if the user would like to participate in a gift card drawing as an incentive to use the application.

3.1.2.2 CycleLane (2012)

CycleLane is used by the Eugene-Springfield metropolitan planning organization (MPO), Lane Council of Governments (LCOG). The application has no significant differences from CycleTracks apart from the data destination and the application name. LCOG seeks to improve local information about bicyclist route choice and validate bicycle route choice models with CycleLane *(Lane Council of Governments 2012)*.

3.1.3 Atlanta, GA – Cycle Atlanta (2012)

Cycle Atlanta was built off the open source codebase of the CycleTracks smartphone application *(Misra et al. 2014)*. Cycle Atlanta was developed by a research team at Georgia Tech while working closely with the City of Atlanta and the Atlanta Regional Commission. Cycle Atlanta includes all of the functions performed by CycleTracks but adds several additional features and uses a different user interface. Screenshots of the user interface can be seen in Figure 3.2.



1. Google Maps API fronts user interface
2. "Notes" can be made about assets or issues
3. Demographic information is entered in the "Settings" sub-menu

Figure 3.2: Cycle Atlanta screenshots (iOS version shown)

In addition to collecting GPS bicycle route data, Cycle Atlanta can also crowdsource information about geo-located bicycle deterrents (pavement issues, traffic signal deficiencies, etc.) or amenities (bicycle parking, water fountains, etc.) (Misra et al. 2014). These deterrents and amenities (called "notes") are selected from a categorical list and can be supplemented with descriptive text and/or a photo. The following notes in Table 3.1 are available for selection:

Table 3.1: Cycle Atlanta Note Selection

Issues/Deterrents	Assets/Amenities
• Pavement issues	• Water fountain
• Traffic signal issue	• "Secret Passage" [11]
• Enforcement request	• Public restroom
• Bicycle parking request	• Bicycle shop
• Bicycle lane design issue	• Bicycle parking
• Custom entry	• Custom entry

Cycle Atlanta also can collect additional (optional) user socio-demographic information: ethnicity and household income (both categorized). It also breaks the age field into categories, instead of requesting a numerical entry. The categories for each field, Table 3.2, are listed below:

[11] "Secret Passage" identifies bicycle-navigable paths that are not on map

Table 3.2: Cycle Atlanta Demographic Categories

Ethnicity	Household Income	Age
• White	• Less than $20,000	• Less than 18
• African American	• $20,000 to $39,999	• 18-24
• Asian	• $40,000 to $59,999	• 25-34
• Native American	• $60,000 to $74,999	• 35-44
• Pacific Islander	• $75,000 to $99,999	• 45-54
• Multi-racial	• $100,000 or greater	• 55-64
• Hispanic/Mexican/Latino		• 65+
• Other		

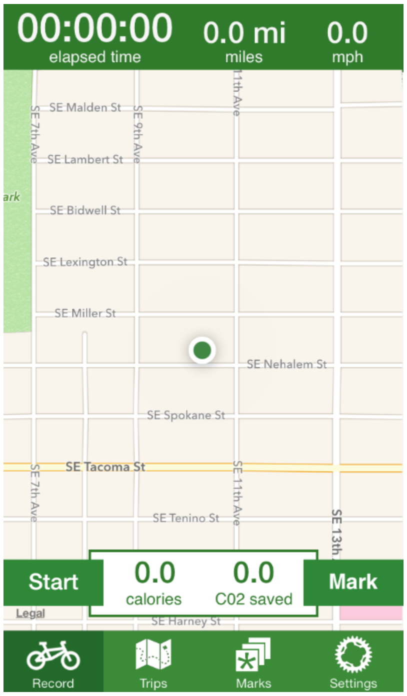
Finally, Cycle Atlanta also collects (optional) data about the type of cyclist using the application:

- The rider can indicate their type using a modified version of Geller's cyclist typology: "Strong & fearless", "Enthused & confident", "Comfortable, but cautious", or "Interested, but concerned".
- The rider can indicate its level of experience/years riding by choosing among these options: "Since childhood", "Several years", "One year or less", "Just trying it out/just started".

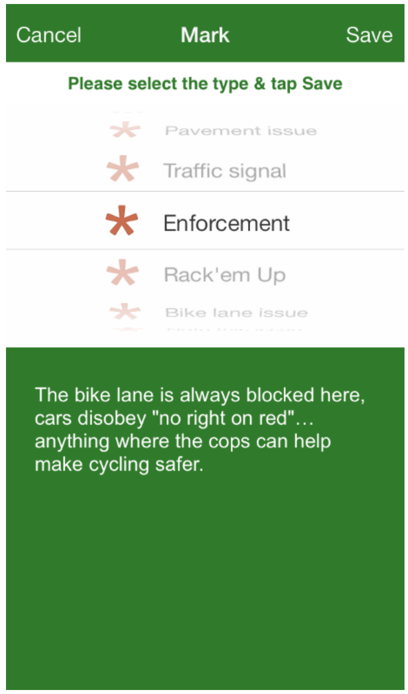
3.1.4 Reno, NV – RenoTracks (2013)

RenoTracks builds on the Cycle Atlanta application (including all of the functions added since CycleTracks). The smartphone application was developed during the 2013 "Hack 4 Reno"[12] coding convention "in order to develop a reliable and accurate method of collecting data from Reno Bicyclists" *(RenoTracks 2013)*. While Cycle Atlanta added several significant new features, RenoTracks has added a customized user interface and the addition of a "CO_2 Saved" counter, which calculates the carbon dioxide that would have been used if a user's trip had been made by automobile instead of bicycle. The customized user interface and CO_2 tracker are shown in Figure 3.3. This app is only available for Apple iPhones as of February 2014, though the Android version is planned to be released within several months.

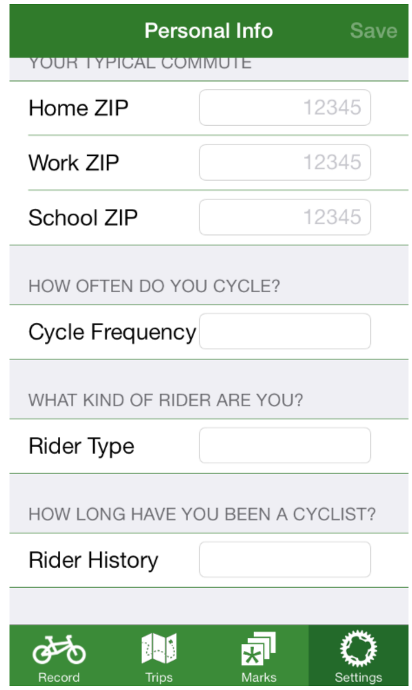
[12] Hack 4 Reno: http://hack4reno.com/



1. Google Maps API fronts user interface



2. “Marks” can be made to denote assets and issues



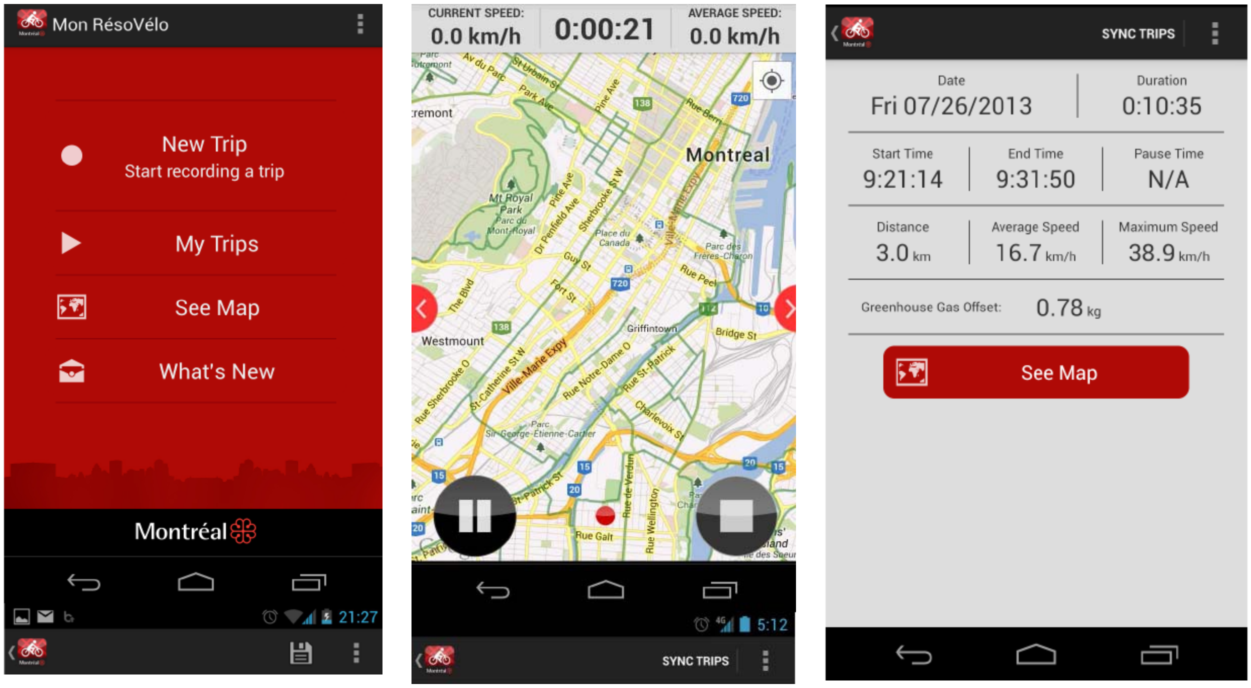
3. Rider typology can be entered into “Settings” sub-menu

Figure 3.3: RenoTracks screenshots (iOS version shown)

3.1.5 Montréal, QC - Mon RésoVélo (2013)

Mon RésoVélo builds on CycleTracks and Cycle Atlanta for a similar application customized for the city of Montréal, Quebec. It was developed as a joint effort between McGill University’s Civil Engineering department and the City of Montréal. Mon RésoVélo does not include the “deterrent and amenity reporting” present in Cycle Atlanta and RenoTracks but their authors claim that the app improves several application functions *(Jackson et al. 2014)*.

The first difference between Mon RésoVélo and prior applications is a difference in user interface design. User interface screenshots are shown in Figure 3.4. The application comes with a complete French language interface which is enabled if the user’s phone has the preferred language set to French. The map interface also highlights bicycle suitable routes (with different facility types notated) in Montréal; a function that none of the other applications reviewed had.



1. Home navigation screen
2. View trip through Google Maps API
3. End of trip summary

Figure 3.4: Example screenshots of Mon RésoVélo interface (Android version shown) *(Jackson et al. 2014)*

The app developers indicate that Mon RésoVélo also restructures the underlying GPS data collection model to "break single trips into a series of segments to manage more easily stopping, pausing, GPS connection loss, and forgetting to turn off GPS collection when finishing a trip" *(Jackson et al. 2014)*.

Finally, Mon RésoVélo adds a greenhouse gas emissions calculator based on local conditions *(Jackson et al. 2014)*. A calorie counter is also included that corrects for cyclist weight, as opposed to RenoTracks which only takes into account trip duration and average speed. Finally, the Mon RésoVélo code is not available, i.e. Mon RésoVélo not an open source code app.

3.1.6 Google Maps

While Google Maps is a navigation application and not a bike route tracker like the CycleTracks derived applications, Google Maps is still quite useful for transportation planners. The Google Maps application has been available as a smartphone application since the advent of the smartphone, but bicycle routes were introduced in July 2013 (though bicycle route finding and directions have been available in the Google Maps web application since 2010). Google Maps has an inventory of bicycle facilities that are shown on the map when cycling is indicated as the desired mode, as shown in Figure 3.5.

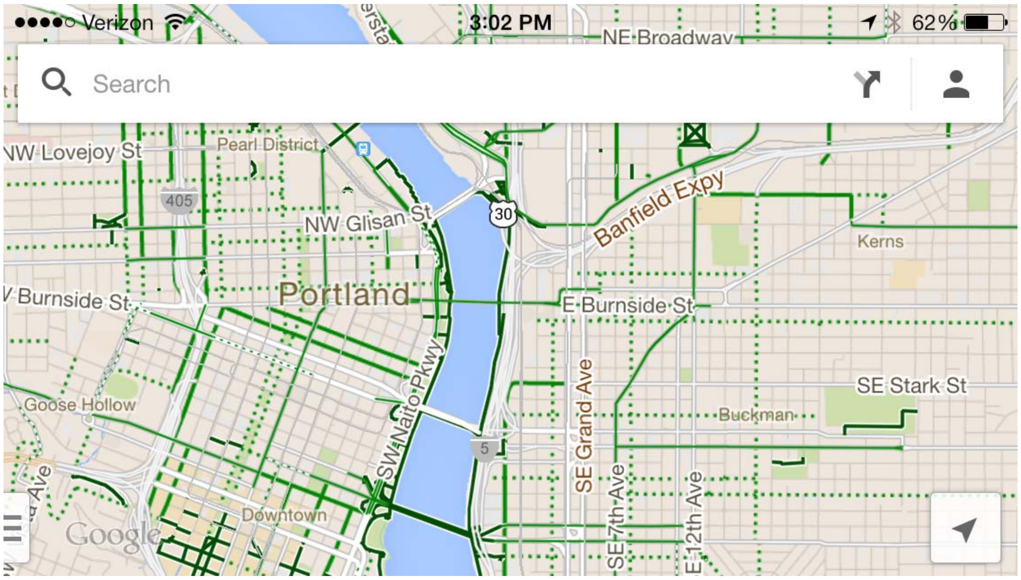


Figure 3.5: Google Maps Screenshot of Bicycle Facilities in Portland, OR (iOS version shown)

Dark green lines indicate separated paths with no motor vehicle traffic, light green lines indicate dedicated bike lanes along a road, and dashed green lines indicate shared lane facilities considered bicycle suitable based on "factors such as terrain, traffic, and intersections" *(Google 2010)*. It is important to note that users of smartphones (and Google Maps) will likely have new bicycle route choices influenced to some degree by Google Maps' algorithms[13].

3.1.7 Planning Application Summary

Table 3.3 compares and summarizes main planning smartphone apps data categories and fields.

Table 3.3: Planning Application Comparison

Data Category	Component	CycleTracks	Mon RésoVélo	Cycle Atlanta	RenoTracks
App		San Francisco, CA	Montréal, QC	Atlanta, GA	Reno, NV
GPS tracking	*Record Trip*	✓	✓	✓	✓
Socio-demographic	*Age*	✓	✓	✓	✓
	E-mail Address	✓	✓	✓	✓
	Gender	✓	✓	✓	✓
	Ethnicity			✓	✓
	Household Income		✓	✓	✓
	Rider Type			✓	✓
	Rider History		✓	✓	✓
	Cycling Frequency	✓	✓	✓	✓
	Winter Cyclist Status		✓		
	Home ZIP	✓	✓	✓	✓

[13] More information about Google's bicycle routing algorithm: http://google-latlong.blogspot.com/2010/03/its-time-to-bike.html

	Work ZIP	✓	✓	✓	✓
	School ZIP	✓	✓	✓	✓
Trip related	*Trip Purpose*	✓	✓	✓	✓
Infrastructure reporting	*Water Fountain*			✓	✓
	Secret Passage			✓	✓
	Public Restroom			✓	✓
	Bike Shops			✓	✓
	Bike Parking Presence			✓	✓
	Other Cycling Asset			✓	✓
Improvement request	*Pavement Issue*			✓	✓
	Traffic Signal Complaint			✓	✓
	Enforcement Issue			✓	✓
	Bike Parking Request			✓	✓
	Bicycle Lane Design Issue			✓	✓
	Other Improvement Request			✓	✓
Useful info for users	*Bicycle Route Map*		✓		
	Trip routes can be viewed after ride	✓	✓	✓	✓
	Average speed and trip distance recorded	✓	✓	✓	✓
	Calorie Counter		✓		✓
	Emission Offset Tracker		✓		✓

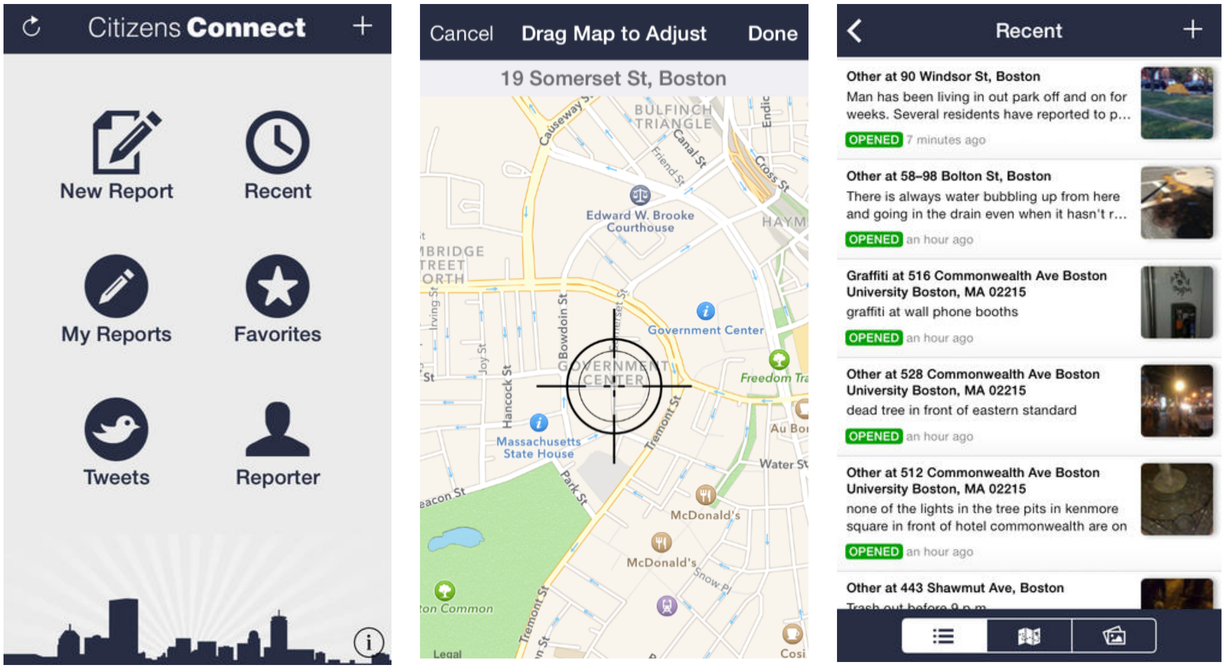
3.2 INFRASTRUCTURE MAINTENANCE AND FEEDBACK

Another type of smartphone app was primarily developed to “crowdsource” information about infrastructure maintenance, enforcement requests, and safety concerns.

3.2.1 Citizens Connect, Boston (2009)

Citizens Connect, first launched in 2009, was one of the first service infrastructure crowdsourcing applications available for smartphones. It allows users to “take pictures of potholes, street light outages, or other public issues, and report them directly to the government” *(O’Brien 2013)*. It has since been used to service over 10,000 requests annually, and approximately 20% of all service requests received by Boston City Hall now come through the application *(New Urban Mechanics 2013)*.

Upon opening the application users can submit a new report; for a new report these are the subject options: pothole, streetlight, graffiti, sidewalk patch, damaged sign, roadway plowing/sanding, un-shoveled sidewalk, or other (custom user input). The service request is geo-located via the device's GPS; a photo and/or text description can be added. Users can also see recent service requests made by other users of Citizens Connect, and whether or not they have been addressed by city employees. Screenshots of the user interface are shown in Figure 3.6.

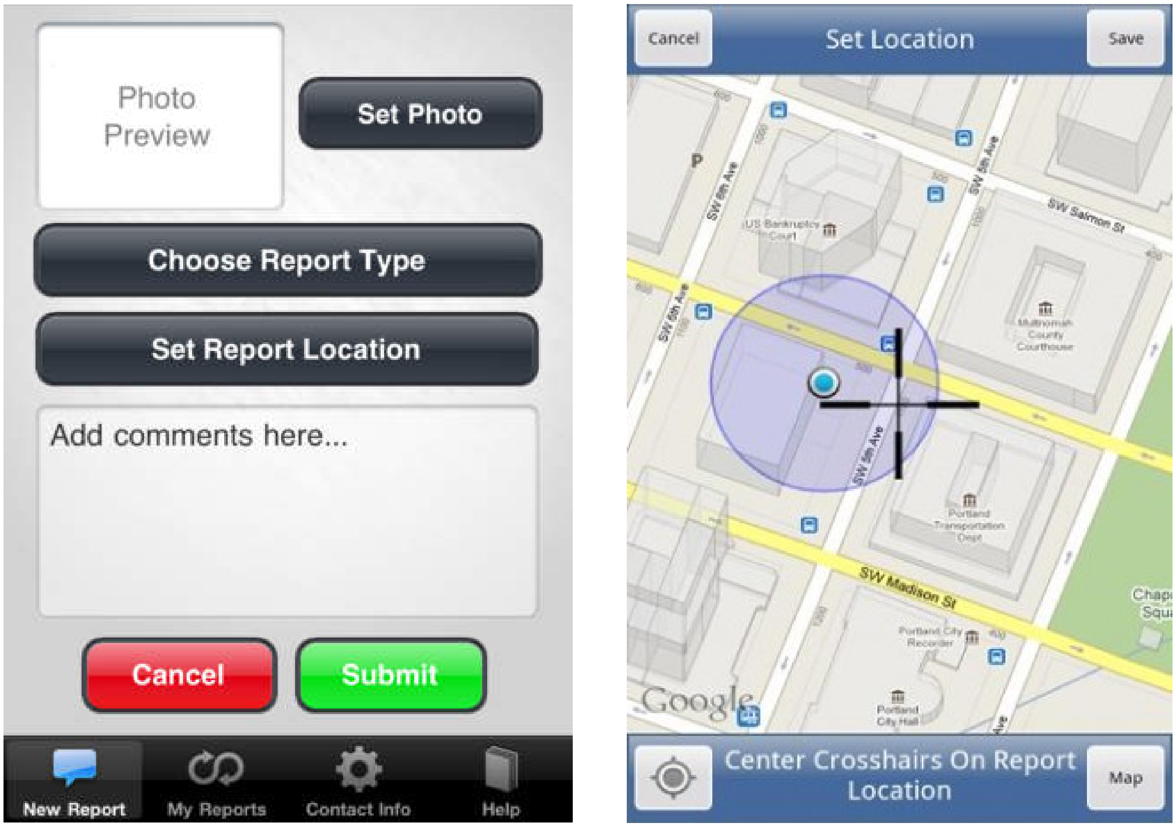


1. Home navigation screen
2. Report location through Google Maps API
3. Recent reports timeline

Figure 3.6: Citizens Connect Screenshots (iOS version shown)

3.2.2 PDX Reporter (2010)

PDX Reporter was released by the City of Portland in 2010 with the goal of streamlining service requests. It offers most of the same functionality as Citizens Connect, though the user interface is different (see Figure 3.7). Users can make geo-located reports with the following subject options: abandoned auto, graffiti, illegal parking, park maintenance, plugged storm drain/inlet, potholes, sidewalk café violations, or street lighting issues. Like Citizens Connect, a photo and/or a brief description can be added to the report.



1. Report filing interface

2. Report location through Google Maps API

Figure 3.7: PDX Reporter Screenshots (iOS version shown)

3.2.3 iBikeEugene (2012)

iBikeEugene was developed by the City of Eugene and the University of Oregon. It was released in 2012. It is a service request application geared specifically towards addressing bicycling road hazards in Eugene. Users can submit geo-located reports with the following subject options: debris in bike lane, bike lane surface hazard, or pick up dead animal. Users can also submit photos and brief descriptions of the issue with the report. Screenshots of iBikeEugene are given in Figure 3.8.

1. Application opening screen
2. Report filing interface
3. Screen shown after report is successfully submitted

Figure 3.8: Screenshots of iBikeEugene application (iOS version shown)

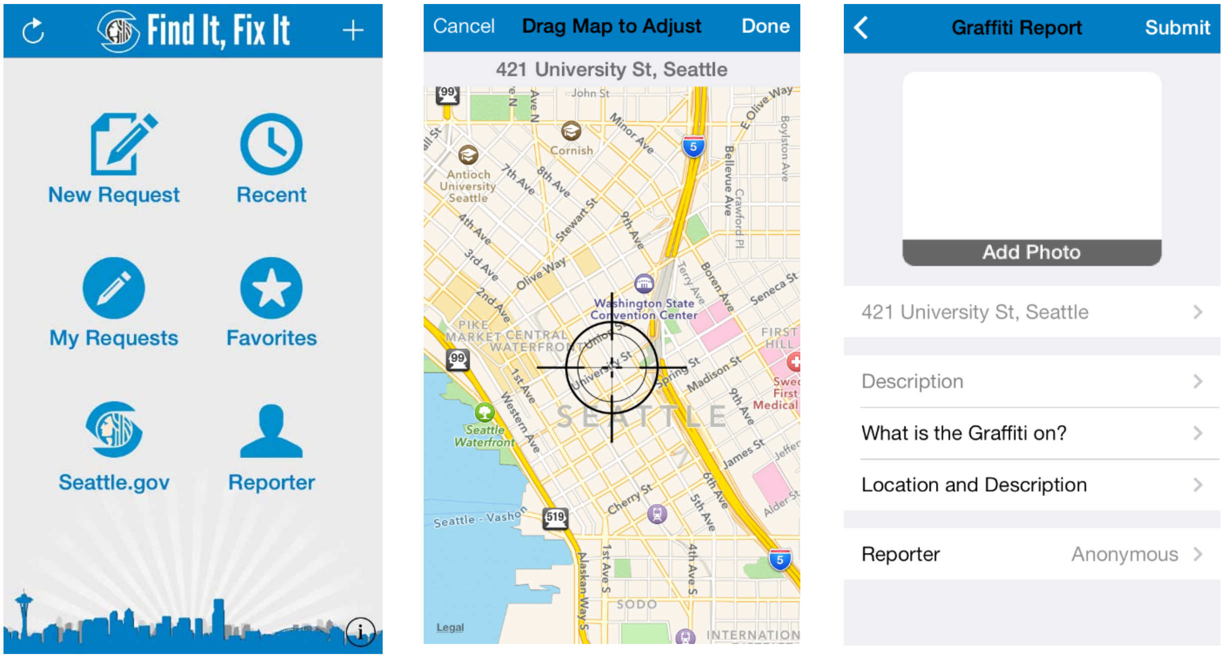
Source: https://play.google.com/store/apps/details?id=gov.eugene_or.pwm.iBikeEugene

3.2.4 SAP Citizen Connect (2012)

Citizen Connect is a general public reporting application developed by SAP Software & Solutions. It can be used in any city and the user (upon first use of the application) is asked to provide the server address of a city's reporting database. Like the other service request applications, it gives the user several categories of reports to choose from: pothole, graffiti, street light malfunctions, parks and green areas, environmental concerns, pedestrian safety, cyclist safety, suspicious activity, or others (custom user input). These categorized (and geo-located) reports allow the user to type a brief description of the concern and attach a photo. The application can also be customized for a specific city.

3.2.5 Find It, Fix It (2013)

Find It, Fix It was released in August 2013 by the City of Seattle. The Find It, Fix It user interface and functionality are nearly identical to Boston's Citizens Connect application, however its categories for service requests are more limited. The following categories can be selected for a report: abandoned vehicle, graffiti report, parking enforcement, pothole, or other inquiry (custom user input). Screenshot examples of Find it, Fix it, are shown in Figure 3.9.



1. Home navigation screen
2. Report location through Google Maps API
3. Report information entry

Figure 3.9: Find It, Fix It Screenshots (iOS version shown)

3.2.6 Other Infrastructure Crowdsourcing Applications

3.2.6.1 General Request or complaint Applications

Many city specific applications have the same basic user interface and functionality because they are versions of the CitySourced[14] application. Areas with branded versions of the CitySourced application included Sedona, AZ; St. Charles, IL; and Douglas County, NE. These applications are simpler and have no category selection available. Each report consists of a GPS location, a short description of the issue, and a corresponding photo.

3.2.6.2 StreetBump

Street Bump was developed by the Boston's Mayor's Office of New Urban Mechanics[15] to detect potholes and other pavement deficiencies. StreetBump is a unique service request application in that the only active input required from the user is for them to record a vehicle trip using their device's GPS. The user can then rest the device on a stable surface within the vehicle and StreetBump uses the device's accelerometer to detect significant "bumps" in the pavement. These bumps are sent with GPS locations to a city's centralized server so that public works employees can go to investigate the bump and determine if it needs to be addressed.

[14] More information on CitySourced: http://www.citysourced.com/default.aspx
[15] More information on New Urban Mechanics: http://www.newurbanmechanics.org/

3.2.7 Infrastructure Maintenance and Feedback Application Summary

Table 3.4 compares and summarizes main infrastructure smartphone apps data categories and fields.

Table 3.4: Infrastructure Maintenance and Feedback Application Comparison

Data Category	Component	PDX Reporter	iBikeEugene	Citizens Connect	Find It, Fix It	Citizen Connect
Location:	-	Portland, OR	Eugene, OR	Boston, MA	Seattle, WA	Anywhere
Application features	*GPS Location*	✓	✓	✓	✓	✓
	Photo Upload	✓	✓	✓	✓	✓
Maintenance requests	*Pothole*	✓		✓	✓	✓
	Clogged Storm Drain or Inlet	✓				
	Park Maintenance	✓				✓
	Streetlight Maintenance	✓		✓		✓
	Graffiti	✓		✓	✓	✓
	Sidewalk Patch			✓		
	Damaged Sign			✓		
	Roadway Plowing or Sanding			✓		
	Unshoveled Sidewalk			✓		
	Other (User identified)			✓	✓	✓
Enforcement requests	*Parking Enforcement*	✓			✓	
	Abandoned Auto	✓			✓	
	Sidewalk Café Violations	✓				
	Environmental Concerns					✓
Safety concerns	*Suspicious Activity*					✓
	Pedestrian Safety					✓
	Cyclist Safety					✓
Bicycle specific hazards	*Debris in Bike Lane*		✓			
	Bike Lane Surface Hazard		✓			
	Dead Animal Clearance		✓			

3.3 RECREATION AND FITNESS

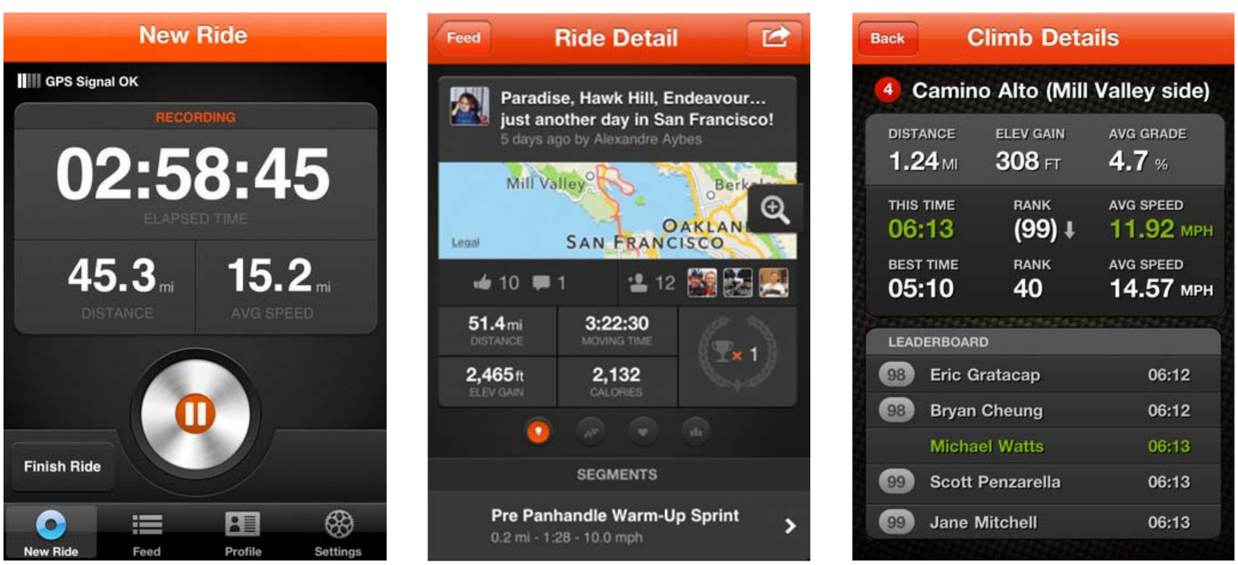
Another type of smartphone application was primarily developed to track recreation or fitness information for users.

3.3.1 MapMyRide

MapMyRide is one of a set of smartphone applications (developed by MapMyFitness) purposed for tracking recreational activities. Any of the applications can be used to track any mode of activity (swim, walk, hike, bike, etc.), but each application is somewhat customized for each mode. The applications can link with a wide array of external sensors (heart rate monitors, bicycle cadence detectors, etc.) to provide relevant fitness statistics. Other users' routes can be viewed through the application, so new users might get ideas for comfortable, fun, or challenging routes. Besides the application, MapMyRide also has a web application that can display summary statistics and graphical displays of a user's trip. The web application can also be used to plan routes ahead of time, so that the smartphone application can direct the user along their preferred route while on their trip.

3.3.2 Strava

Strava was released in 2009 as a web application and a smartphone application for the iOS and Android platforms. Like MapMyRide, users can track their routes via a device's GPS, and view them afterwards through either the smartphone application or website. Summary statistics like speed, distance, and trip time are displayed, as well as graphical representations of the route profile and plan overview. However, Strava does offer some additional functionality for users in that it tracks performance on common segments of multiple users. This enables users to virtually "compete" for best segment time, maximum speed, and other top statistics. Through this functionality, the application becomes a bit more social than other mapping applications like MapMyRide and MyTracks. Screenshots of Strava are shown in Figure 3.10.



1. Ride recording interface 2. Ride overview 3. Across user's segment comparison

Figure 3.10: Strava screenshot examples (iOS version shown)

ODOT has been collaborating with Strava and contracted with Strava in 2014 to purchase an Oregon-wide 2013 dataset. The statewide dataset provides the number of Strava users by roadway segment by time and day during 2013. Members from the ODOT Transportation Planning and Analysis Unit (TPAU) commented that: "while there currently is not a method to expand this information up to total bike riders, the relative amount of use from STRAVA users from one path to another does provide ODOT with more guidance than has existed previously on which routes are used more than others. The data currently purchased from STRAVA does not provide information on user comfort (level of traffic stress) on a given segment. Additionally there is no way to determine which types of Oregon riders are represent in the dataset; STRAVA users are likely not a fully representative sample".

3.3.3 MyTracks

MyTracks was developed by Google in 2011 as a separate application that takes advantage of their extensive mapping software capabilities. It is only available for the Android platform. Like CycleTracks and applications that followed it, MyTracks will track a user's GPS location while they are running, cycling, hiking, driving, or using any other mode of transportation. MyTracks reports summary statistics at the end of trip, like average speed, maximum speed, distance covered, and elevation climbed. These and other summary statistics can be easily exported to Google's suite of cloud-based office software. Besides being able to view a trip horizontally, a user can also see an elevation profile of their trip. Trips can also be exported to be displayed in Google Earth or analyzed in other software.

3.3.4 Recreational Application Unique Features

Recreational applications unique features include:

- Both Strava and MapMyRide allow users to see other user's routes and summary statistics, giving them a social networking aspect.

- Strava and MapMyRide allow for exporting of data for viewing and analysis in other software.

- Strava gives users the ability to "compete", which adds additional functionality and attractiveness to the application. Users can "climb the leaderboards", set personal records, earn course record honors, and join monthly challenges.

Strava is likely to attract competitive and experienced riders. It is likely that the databases of preferred cycling routes from MapMyRide or Strava are not representative of all bicyclist groups (e.g. Interested but Concerned riders).

3.4 BLOS AND SMARTPHONE DATA COLLECTION OPPORTUNITIES

One of the key advantages of smartphone data is the collection of some user demographic data and Global Positioning System (GPS) data. The collection of GPS points can be matched into segments and intersections of the road and bicycle network. For each trip, detailed paths can be constructed.

As discussed in the previous sections, BLOS methods rely on data collected or measured in the field. Hence, smartphone detailed route data will not likely provide data that can be inputted directly into BLOS methods. However, BLOS methods have been calibrated or estimated in most cases finding statistical relationships between variables that can be measured or observed in the field and users' perceptions of the facilities. Users' perceptions are usually stated preference data and elicited utilizing video or surveys. Many of the videos of facilities and biking conditions may not compare well with Oregon facilities and biking conditions since they are from Florida. The smartphone data is revealed preference data that can be potentially used to calibrate or estimate Oregon specific BLOS methods based on field data.

Among the four types of smartphone applications, transportation planning and infrastructure maintenance or feedback are the most relevant to ODOT's mission. Smartphone transportation planning applications typically collect GPS route data and some additional socio-demographic, trip purpose, and in some cases some infrastructure data. Infrastructure reporting applications do not usually collect socio-demographic or trip related data. ODOT data needs may require the collection of additional data. However, the collection of additional data must be justified because the level of user burden must be also considered. A high level of user burden may reduce the sample size or introduce self-selection bias.

Smartphone data are clearly more useful for methods that analyze bicycle networks (e.g. CZA and LTS methods) and for methods that can aggregate users into user groups (e.g. the LTS method). The revealed path data can be grouped by user groups to estimate network properties such as detour percentage, i.e. the distance of actual bicyclists' paths vs. the distance of the shortest possible paths connecting the same origins and destinations. According to the LTS methods, detours that are beyond 25% would indicate that there is stressful link or segment. The network BLOS methods are especially useful for analyzing areas with immature bicycle networks or a lack of available data.

ODOT has adopted a LTS-based procedure to analyze the bicycle mode in the multimodal analysis chapter of the Analysis Procedures Manual. The LTS classification of stress levels as a function of road characteristics is adopted from Dutch design standards. The revealed preference data provided by the smartphone application can be potentially used to calibrate or estimate Oregon specific LTS classifications or factors.

4.0 DATA AVAILABILITY

Data availability at each organization is documented below. Data is categorized into geocoded data and "other" (non-geocoded) data. In general, agencies had much more non-geocoded information related to bicycle routes and infrastructure, such as bicycle master plans or system inventories. Geocoding all of this data would substantially increase the ability to conduct statewide BLOS estimation. BLOS data parameters available from the inventoried datasets at each organization are summarized at the end of this chapter, in Table 4.12.

4.1 DATA TYPES

Different types of data are available that can contribute to BLOS estimation in Oregon. If not already available in a geocoded format for use with a Geographic Information System (GIS), these data will have to be converted to geocoded formats in order to correspond with the GPS traces of application users. Three types of data will be inventoried:

1. **Bicycle Designated Route Data**:

   These data consist of *designated* bicycle routes throughout Oregon, whether that is at the state, regional, municipal, or university level. Routes can have varying types of bicycle infrastructure accommodations, but they are signed and/or mapped to be suitable for bicycles, and thus likely have an impact on bicyclists' route choice. Therefore, it is pertinent to know what corridors are considered bicycle routes for consideration in BLOS estimation.

2. **Bicycle Infrastructure Data**:

   Bicycle infrastructure data comprises the bulk of BLOS estimation methods. This would include bicycle facility type and relevant geometric measurements. Greater bicycle infrastructure data coverage and resolution will lead to more precision in estimating BLOS.

3. **Bicycle Demand Data:**

   Bicycle demand data includes bicycle volume counts and estimated mode shares from travel surveys. In locations where this is available, this will aid in allowing the GPS traces collected to correspond to actual cyclist volumes, which is useful in BLOS estimation.

4.2 DATA INVENTORY METHODOLOGY

The first step on inventorying available bicycle data was searching for the relevant data types on agency web sites. If adequate data were not available on the web site for public use, e-mail inquiries were sent to each agency. Nearly every agency asked responded to our inquiry, whether they had relevant data available or not. The only inquiry unanswered was that sent to the University of Oregon. The agencies contacted are listed in Table 4.1.

Table 4.1: Agencies Contacted and Response Status

	Response?	
Agencies Asked	**Yes**	**No**
State		
Oregon Department of Transportation	✓	
MPO		
Metro (Portland Area)	✓	
Mid-Willamette Valley COG (Salem-Keiser area)	✓	
Corvallis Area MPO	✓	
Central Lane MPO (Eugene-Springfield area)	✓	
Bend MPO	✓	
Rogue Valley MPO (Ashland-Medford area)	✓	
City		
Portland	✓	
Salem	✓	
Corvallis	✓	
Eugene	✓	
Bend	✓	
Ashland	✓	
Medford	✓	
University		
Portland State University	✓	
Oregon State University	✓	
University of Oregon		✓

4.3 STATE LEVEL

4.3.1 Oregon Department of Transportation (ODOT)

ODOT has its own GIS file transfer protocol (FTP)[16] web site where available GIS layers can be downloaded. The date modified (as of the March 2014 inventory this report is based on) is listed alongside the GIS layer file. Data layers that were relevant to BLOS were downloaded to be stored in a centralized area for the remainder of this project. The relevant layers are listed in Table 4.2. A key limitation of this dataset is that it covers almost exclusively on state-owned facilities and excludes local roads where a significant portion of bicycling occurs.

ODOT's existing and "needed" bicycle facilities are mapped across the state, including both bike lanes on state roads, shared lane treatments on state roads, and bicycle suitable shoulders on state roads. The following BLOS attributes are identified within the existing bicycle facility data layer:

[16] ODOT FTP Site: ftp://ftp.odot.state.or.us/tdb/trandata/GIS_data/

- Bicycle facility type (Bike lane, shared lane, or shoulder)
- Side of road (right, left)
- Bicycle facility width (feet)
- Bicycle facility condition (Fair, Poor, Good)
- Bicycle facility notes (poor striping, width varies, etc.)

Table 4.2: ODOT data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Statewide AADT	November 2012	ODOT FTP Web Site
Existing Bicycle Facilities	September 2013	ODOT FTP Web Site
Needed Bicycle Facilities	September 2013	ODOT FTP Web Site
Highway Network	March 2013	ODOT FTP Web Site
Lane Width	December 2013	ODOT FTP Web Site
Medians	December 2012	ODOT FTP Web Site
Number of Lanes	December 2012	ODOT FTP Web Site
Pavement	May 2011	ODOT FTP Web Site
Posted Speed Limit	September 2013	ODOT FTP Web Site
Rail Crossings	April 2010	ODOT FTP Web Site
Shared Use Paths	September 2013	ODOT FTP Web Site
Shoulder Width	September 2013	ODOT FTP Web Site
Surface Width/Type	December 2012	ODOT FTP Web Site
Existing Sidewalks	September 2013	ODOT FTP Web Site
Needed Sidewalks	September 2013	ODOT FTP Web Site

The "bicycle facility need" layer highlights areas of state roads that ODOT considers in need of bicycle accommodation.

A number of BLOS measures could be calculated based completely on the data available for ODOT's facilities: BSIR[1], BSL[2], BSS[8], BLOS[16], BLOS[19], BLOS[20], and LTS[21]. See Table 2.4 for references. Many of the other methods could also be calculated with assumptions made for some of the parameters.

ODOT had several bicycle counting efforts around the state, including the loop counter in the I-205 trail in Portland and the tube counter on the Historic Columbia River Highway Trail near the town of Cascade Locks. More information about ODOT's bicycle counting initiatives is available in a recent research report documenting non-motorized transportation counting efforts around the state of Oregon *(Figliozzi et al. 2014)*.

4.3.2 Oregon Household Activity Survey (OHAS)

The Oregon Household Activity Survey (OHAS) was conducted by the Oregon Modeling Steering Committee (OMSC) over the period of April 2009 to November 2011 and asked 17,000 households to identify their travel patterns and demographic characteristics by answering survey questions. The results are used by ODOT and MPOs to calibrate statewide and regional travel demand models. OHAS is one source of estimating bicycle mode shares in different regions of Oregon, which will provide a useful benchmark in data collection and analysis. However, in many cases, the sample size for bike trips is quite small.

4.4 METROPOLITAN PLANNING ORGANIZATION LEVEL

There are six Metropolitan Planning Organizations (MPOs), one for each urbanized area with a population of over 50,000 in Oregon. A map of the geographic distribution of MPOs is given in Figure 4.1. Many transportation planning functions are handled by MPOs instead of or in addition to state and local agencies, so their datasets are important to incorporate into this inventory.

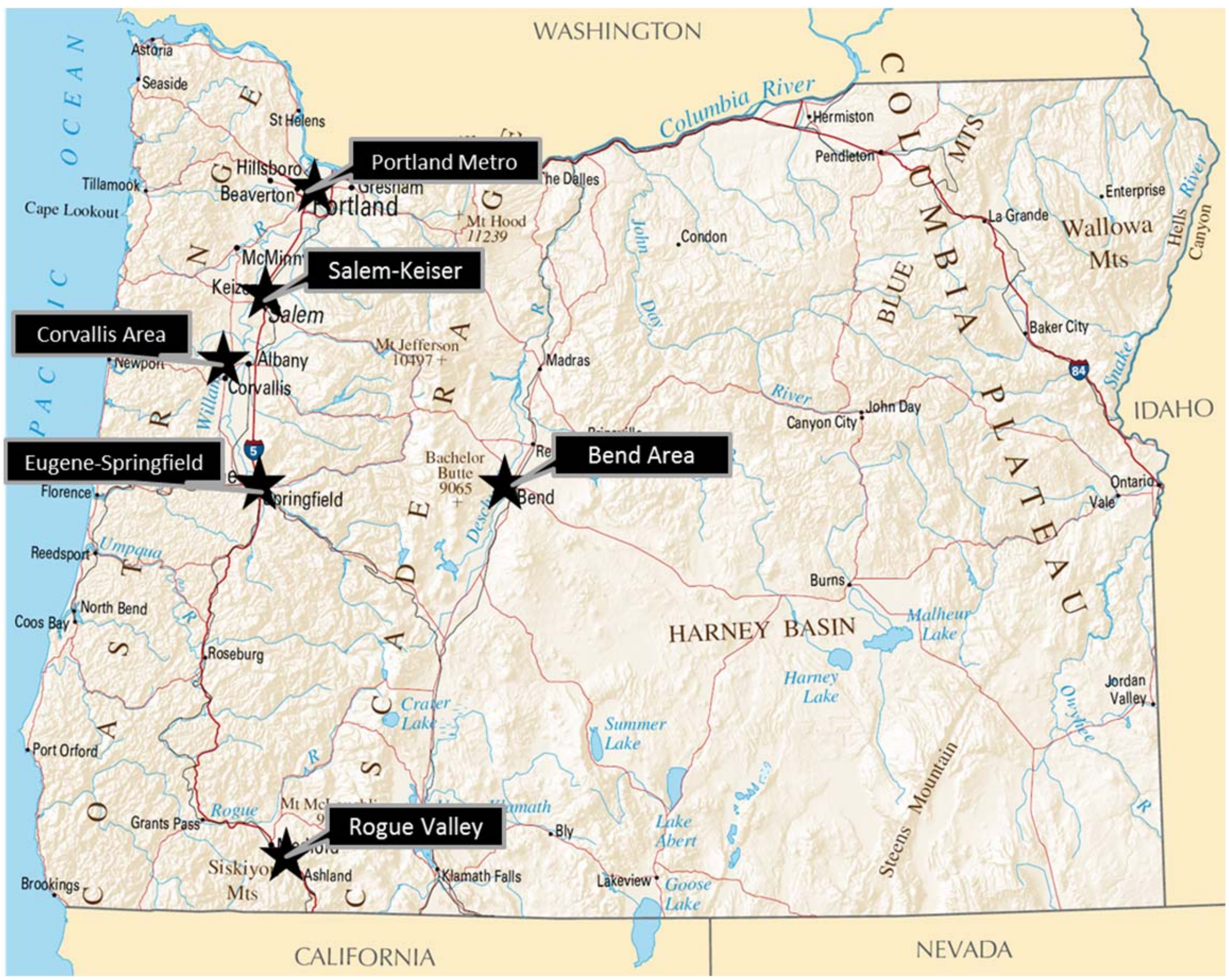


Figure 4.1: Oregon Metropolitan Planning Organization Map

4.4.1 Metro (Portland)

Metro is the MPO for the Portland metropolitan area. Metro has a wide availability of GIS data through their Regional Land Information System (RLIS)[17]. Most of the data layers available through RLIS can be downloaded by anyone free of charge, while some (such as zoning) are only available if a subscription is purchased. The layers are updated periodically as changes are made to the physical land features. Portland State University has a subscription to RLIS, so all BLOS relevant data layers were downloaded into the working inventory. The relevant data layers are listed in Table 4.3.

Table 4.3: Oregon Metro data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Arterial Streets	January 2014	RLIS
Existing & Planned Bicycle Facility Network	May 2010	RLIS
Existing & Planned Light Rail Network	October 2013	RLIS
Existing & Planned Light Rail Stations	January 2014	RLIS
Generalized Zoning	January 2014	RLIS
Major Arterials	January 2014	RLIS
Railroad	April 2013	RLIS
Sidewalks	August 2012	RLIS
Streets	January 2014	RLIS
Topographic Contours	July 2002	RLIS
TriMet Bus System (Routes)	January 2014	RLIS
TriMet Bus System (Stops)	January 2014	RLIS

Metro's existing and planned bicycle network layer identifies facility type, so assumptions about geometry would have to make in order to perform BLOS calculations using this layer. Metro considers a wide range of bicycle accommodations in their bicycle facility typology. The following bicycle facility types are considered:

- Regional multi-use path
- Local multi-use path
- Bike boulevard
- Bike lane
- Low traffic road
- Moderate traffic road

[17] RLIS website: http://www.oregonmetro.gov/index.cfm/go/by.web/id/593

- High traffic road
- Caution area

Metro has a conducted extensive analysis of the Portland metropolitan area's bicycle network. One assessment uses the Cycle Zone Analysis method (discussed in Task 1) to categorize zones in Portland in terms of their current bikeability and their potential for future bikeability. This particular report[18] informs Metro's Regional Active Transportation Plan[19]. Metro's analyses will be useful in drawing conclusions about bicycle preferences from the Portland area. Metro also currently collects bicycle counts from a variety of its regional nature trails *(Figliozzi et al. 2014)*.

4.4.2 Mid-Willamette Valley Council of Governments (Salem-Keizer)

The Mid-Willamette Valley Council of Governments (MWVCOG) is the MPO for the Salem-Keiser metropolitan area. A bicycle facility inventory and bicycle route designations were available as GIS layers for the three-county area (Marion, Polk, and Yamhill counties). This inventory was made available through correspondence with Ray Jackson, Senior Planner at MWVCOG[20]. Some additional GIS layers were also available for the metropolitan area through the MWVCOG web site[21]. (Table 4.4)

Table 4.4:BLOS Relevant Data Layers and Data Sources

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bicycle Facility Inventory (existing & planned)	2013	Correspondence with Ray Jackson
Bicycle Route Designations	2013	Correspondence with Ray Jackson
Zoning	May 2012	MWVCOG Web Site
Railroad	May 2012	MWVCOG Web Site
Street Network	May 2012	MWVCOG Web Site

The bicycle facility inventory for the Salem-Keiser area indicates the following attributes for roads where applicable:

- Is this street/road suitable for bicycles? (yes/no)
- Is this bicycle facility existing or planned?
- Facility type (Bike lane, shared lane)

[18] Metro Regional Bicycle Network Evaluation: http://library.oregonmetro.gov/files/bikeeval_final_report.pdf
[19] Metro Regional Active Transportation Plan: http://www.oregonmetro.gov/index.cfm/go/by.web/id/39005
[20] Ray Jackson, Senior Planner, Mid-Willamette Valley Council of Governments, rjackson@mwvcog.org. Data received on March 17th, 2014
[21] MWVCOG Web Site for Zoning Layer: http://www.mwvcog.org:8080/2/document-folder/data-and-reports/school-district/GIS%20Data%20May%202012.zip/view?searchterm=gis

- Qualitative traffic volume level (high, medium, or low)
- Should bicyclist be cautious on this street/road? (yes/no). This is identified by the Salem Department of Public Works on their bicycling map. These are areas of high traffic volumes, low cyclist visibility, or areas where crashes have happened previously.
- Is there an incline on this road? (moderate, steep, or very)
- Non-comprehensive shoulder measurements of varying widths (i.e. only available where measured)

4.4.3 Corvallis Area MPO

The Corvallis Area MPO (CAMPO) is the MPO for the Corvallis metropolitan area. No GIS data were available directly from the MPO. However, as reviewed in section 4.5.3, extensive GIS data was available from the City of Corvallis.

2012 and 2013 bicycle counts at specific segments and intersections in the Corvallis area were available in tabular form on the CAMPO web site[22]. This data can be geocoded (if necessary) to compare with the data recorded with the smartphone application database.

4.4.4 Central Lane MPO (Eugene-Springfield)

The Central Lane MPO (CLMPO) is the MPO for the Eugene-Springfield metropolitan area. CLMPO had both bicycle and street networks available in geocoded format, as well as selected geocoded bicycle counts. The bicycle and street networks were transferred through FTP to our inventory courtesy of Josh Roll, Associate Planner for the Lane Council of Governments (LCOG) and a member of this project's TAC[23]. Bicycle counts are available through CLMPO's regional bicycle counting program[24]. Zoning is available through CLMPO's Regional Land Information Database (RLID) [25]. These layers are summarized in Table 4.5.

Table 4.5: Central Lane MPO data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Street Network	2013	LCOG FTP
Bicycle Facility Network	2013	LCOG FTP
MPO Bicycle Counts	Continually updated	CLMPO Bicycle Counts
Zoning	Continually updated	RLID

The bicycle facility network layer in the Eugene-Springfield area is part of CLMPO's regional travel demand model, and identifies the type of bicycle facility (shared roadway, bike lane, or

[22] CAMPO Bike Counts: http://www.corvallisareampo.org/Page.asp?NavID=31
[23] Correspondence with Josh Roll (LCOG), JRoll@lcog.org
[24] http://maps.rlid.org/ArcGIS/rest/services/MPO/BicycleCounts/MapServer
[25] http://www.lanecounty.org/Departments/IS/GIS/Pages/datasales.aspx

multi-use path) as well as the estimated motor vehicle traffic volume on streets where counts are available. Bicycle counts are also mapped where they are available.

4.4.5 Bend MPO

The Bend MPO (BMPO) is the MPO for the Bend metropolitan area. BMPO has a regional bicycle counting program, with geocoded counts available for analysis. Some additional geocoded data layers were available as well via private correspondence[26], as listed in Table 4.6. All the layers available through BMPO are shown on their interactive mapping site[27], but the data is not available publicly and must be requested. There is also a bicycle route evaluation initiative in its infancy in the Bend area which seeks to gauge the friendliness and suitability of different bicycle routes. The insight provided by this critical thinking may be invaluable when BLOS is eventually evaluated for the Bend area with data from the application.

Table 4.6: Bend MPO data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bicycle Facility Network (existing & planned)	2006	Correspondence with Jovita Anderson
Bicycle Trails	2013	Correspondence with Jovita Anderson
Bicycle Counts	May 2013	Correspondence with Jovita Anderson
Street Network	2013	Correspondence with Jovita Anderson
Traffic Counts	2013	Correspondence with Jovita Anderson
Bus Routes	2013	Correspondence with Jovita Anderson
Sidewalks	2013	Correspondence with Jovita Anderson
Railroad	2013	Correspondence with Jovita Anderson
Zoning	2013	Correspondence with Jovita Anderson
Transportation SDC Intersections and Segments	2013	Correspondence with Jovita Anderson

Bend MPO's bicycle facility network layer was assembled for their Transportation System Plan (TSP)[28] in 2006. It contains information about facility type (shared roadway, bicycle lane, or multi-use path) and whether it exists or is planned. There is also a layer available for recreational bicycle trails, though not all are suitable for all types of cyclists, as some are indicated to be unpaved trails. Bicycle counts are also available at selected locations from a bicycle counting initiative undertaken in May 2013.

4.4.6 Rogue Valley MPO

The Rogue Valley MPO (RVMPO) is the MPO for the Ashland-Medford metropolitan area. While the RVMPO did not have GIS data itself, we were directed to Jackson County which had

[26] Correspondence with Jovita Anderson (BMPO), janderson@bendoregon.gov
[27] BMPO Interactive Mapping Site: https://maps.ci.bend.or.us/Public/default.aspx?config=Public
[28] http://www.ci.bend.or.us/modules/showdocument.aspx?documentid=4091

several layers relevant to BLOS estimation. The GIS layers were available at a public FTP site[29]. The GIS layers made available by Jackson County are listed in Table 4.7.

Table 4.7: Jackson County data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bicycle Facility Network (Existing & Planned)	March 2010	Public FTP
Driveways	March 2014	Public FTP
Parking Locations	March 2010	Public FTP
Railroads	June 2010	Public FTP
Street Network	March 2014	Public FTP
Traffic Signals	July 2010	Public FTP

The bicycle facility network layer for Jackson County identifies the type of bicycle facility (shared roadway, bicycle-suitable shoulder, bike lane, or multi-use path).

Jackson County has several EcoCounters in place for continuous bicycle count data. The login to the EcoCounter web site for Jackson County was given to the research team for use if deemed beneficial. Through the EcoCounter website, counts can be downloaded for the lifetime of the counter in many different formats for different analysis types.

4.5 CITY LEVEL

4.5.1 Portland

The city of Portland is the most populous municipality in Oregon and is the central city of the Portland metropolitan area. Portland is also home to Portland State University. Many transportation engineering and planning functions are performed by the various agencies within the City of Portland, the primary agency of interest being the Portland Bureau of Transportation (PBOT). PBOT designs and constructs many of the bicycle facilities in Portland itself, though some are designed by consultants and/or constructed by contractors. PBOT manages and maintains most of the bicycle facilities within the city of Portland, except for those in county or state jurisdictions, such as the bicycle facilities on bridges managed by counties. PBOT has GIS-ready data[30] pertaining to its bicycle network as well as other BLOS relevant data. (Table 4.8)

[29] Jackson County FTP: http://gis.jacksoncounty.org/Portal/gis-data.aspx
[30] City of Portland GIS Portal: https://www.portlandoregon.gov/bts/article/268487

Table 4.8: City of Portland data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bicycle Facility Network (Existing & Planned)	September 2013	PBOT GIS
Bicycle Parking	September 2013	PBOT GIS
Curbs	September 2013	PBOT GIS
Pavement Maintenance Status	September 2013	PBOT GIS
Parking Meters	September 2013	PBOT GIS
Percent Slope	September 2013	PBOT GIS
Sidewalks	September 2013	PBOT GIS
Street Network	September 2013	PBOT GIS
Street Trees	September 2013	PBOT GIS
Traffic Signals	September 2013	PBOT GIS
Traffic Calming Devices	September 2013	PBOT GIS
Transit Stations	September 2013	PBOT GIS
Zoning	September 2013	PBOT GIS

A bicycle facility network was available from the City of Portland, though much of the data is duplicated by the layer available through Metro. The bicycle facility network layer for Portland identifies the bicycle facility type (Bicycle Boulevard, signed connection, bike lane, or multi-use path).

There are also extensive bicycle counting programs administered and/or managed by PBOT. Short term bicycle counts are recorded annually at various locations around the city. These data are available online[31], and can be geocoded if beneficial to the eventual analysis of smartphone data. Several other permanent bicycle counting locations are available through PORTAL[32] *(Figliozzi et al. 2014)*.

4.5.2 Salem

Salem is Oregon's capital city and home to many state government offices, including ODOT's state headquarters and its Region 2 offices. The City of Salem had several data layers that will prove useful in GIS evaluation. The Salem Department of Public Works (DPW) has curbs and speed zones available[33] as GIS layers, while the City of Salem general GIS website[34] had bike routes, street network and other GIS layers available. The layers available through the City of Salem are listed in Table 4.9.

[31] PBOT Bicycle Counts: https://www.portlandoregon.gov/transportation/44671
[32] PORTAL Bike Counting: http://demo.portal.its.pdx.edu/Portal/index.php/pedbike
[33] City of Salem DPW GIS Portal:
http://www.cityofsalem.net/Departments/PublicWorks/Engineering/Pages/MetaData.aspx
[34]City of Salem GIS Portal: http://www.cityofsalem.net/Departments/ITandFacilities/GIS/Pages/GISData.aspx

Table 4.9: City of Salem data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Curbs	April 2006	Salem DPW GIS
Speed Zones	April 2006	Salem DPW GIS
Bike Routes	2013	Salem GIS
Parking	2013	Salem GIS
Sidewalks	2013	Salem GIS
Street Centerline Network	2013	Salem GIS
Land Use Planning	2013	Salem GIS
Topography	2013	Salem GIS
Zoning	2013	Salem GIS

4.5.3 Corvallis

The City of Corvallis had many GIS data layers related to BLOS estimation available through their web site[35]. The available data layers are listed in Table 4.10. Corvallis is home to Oregon State University.

Table 4.10: City of Corvallis data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bike Lanes	June 2013	Corvallis GIS Portal
Topography	January 2014	Corvallis GIS Portal
Intersections	June 2013	Corvallis GIS Portal
Multi-Use Paths	June 2013	Corvallis GIS Portal
Parking Stalls	June 2013	Corvallis GIS Portal
Railroads	June 2013	Corvallis GIS Portal
Street Lights	June 2013	Corvallis GIS Portal
Street Network	June 2013	Corvallis GIS Portal
Transit Routes	June 2013	Corvallis GIS Portal
Transit Stops	June 2013	Corvallis GIS Portal
Zoning	January 2014	Corvallis GIS Portal

Instead of mapping the bicycle network in one layer as many of the other jurisdictions did, the multi-use paths and bike lanes are separately identified. No further information about the bicycle facilities is available from the layer files.

4.5.4 Eugene

Eugene is home to the University of Oregon. The city of Eugene did not have any of its own data available, as the regional agencies CLMPO and LCOG manage the bicycle route, infrastructure

[35] City of Corvallis GIS Portal: http://www.corvallisoregon.gov/index.aspx?page=163

and count inventories for Eugene. They have made GIS data available pertaining to bicycle routes and infrastructure, as discussed in section 4.4.4.

4.5.5 Bend

The City of Bend responded that they were not able to provide any data that would be helpful to the project, but instead forwarded me to the Bend MPO as discussed in section 4.4.5.

4.5.6 Ashland and Medford

Ashland and Medford are the principal cities within Rogue Valley MPO. Medford has a GIS server that can be accessed through instructions available on their web site[36]. Several BLOS relevant data layers are available through this server for the jurisdiction of the City of Medford. These layers are listed in Table 4.11.

Table 4.11: City of Medford data available as GIS layers

BLOS Relevant Data Layers	Month & Year Last Updated (as of March 2014 Inventory)	Data Source
Bicycle Parking (Downtown)	2013	Medford GIS Server
Boundaries	2013	Medford GIS Server
Street Network	2013	Medford GIS Server
Tax Lots	2013	Medford GIS Server
Topography	2013	Medford GIS Server

The City of Ashland had a GIS layer describing the current and planned off-street bicycle facilities in Ashland. This was transferred to our inventory through private correspondence with Jason Wegner, GIS Manager at the City of Ashland[37]. Much of the data overage in Ashland was also available through Jackson County, which was summarized in the Rogue Valley MPO section 4.4.6 of this report.

The City of Ashland commissioned a Transportation System Plan update that was finalized in 2012, with the final report being prepared by Kittleson and Associates[38]. Within this report, many elements of the transportation system in Ashland critical to BLOS estimation are inventoried, including the street network, bicycle network, and bicycle volumes. Some of this information can be leveraged during analyses of BLOS and bicyclist route preference in Ashland.

[36] Medford GIS Server access: https://www.medfordmaps.org/gis-map-services.aspx
[37] JasonWegner, GIS Manager at the City of Ashland, wegnerj@ashland.or
[38] Ashland TSP: http://www.ashland.or.us/Files/Final%20TSP_2013-04-23.pdf

4.6 UNIVERSITY LEVEL

4.6.1 Portland State University (Portland)

Portland State University (PSU) has conducted a wide range of research related to bicycle travel in the past several years. Some of the data resulting from these projects may be useful and accessible if deemed beneficial to the outcome of this project.

The study most readily applicable to this project is the Oregon Transportation Research and Education Consortium (OTREC) report authored by Dill and Gliebe *(Dill and Gliebe 2008)*, which examined the route choice preferences of a sample of Portland cyclists using GPS units. One of the primary results of this study applicable to BLOS evaluation tools was the significant revealed preference for more comfortable bicycle facilities. However, this revealed preference was uncovered because of the high resolution bicycle facility data available through Metro's RLIS (see section 4.4.1). The methodology of this study might help inform the eventual data analysis methodology of this project, as several of the same procedures, such as GPS data cleaning and map matching, will have to be conducted.

PSU's PORTAL[39] has extensive information pertaining to automobile and transit volumes in the Portland metropolitan region. This data might be useful where traffic volumes are not existent in current GIS data layers in the region. The PORTAL team is also currently in the process of integrating pedestrian and bicycle counts into its database through a pooled fund research with several Oregon and national communities.

4.6.2 Oregon State University (Corvallis)

Oregon State University has also recently conducted research related to bicycle transportation planning and engineering concerns. Dr. Haizhong Wang[40] and graduate student Matthew Palm utilized Bicycle Level of Traffic Stress (BLTS) to evaluate bicycle networks, network connectivity, and compare the results to geocoded bicycle crash data and pavement conditions in Corvallis, OR. The aim of this comparison is to detect spatial patterns in the distribution of bicycle crashes as they relate to BLTS measures. The database that Dr. Wang has built for this project can likely be leveraged for specialized analysis of the bicycle network in the Corvallis area.

4.6.3 University of Oregon (Eugene)

At the University of Oregon there is research taking place investigating the use of smartphone applications as a means of crowdsourcing transit user data[41], which could prove useful during the development and testing of ODOT's application. Another project investigates how mobile mapping applications can facilitate improved dialogue between transportation agencies and the general public[42].

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[39] PORTAL website: http://portal.its.pdx.edu/Portal/index.php/home
[40] Personal correspondence: Dr. Haizhong Wang, Assistant Professor of Civil Engineering, Oregon State University
[41] http://trid.trb.org/view/2014/P/1279729
[42] http://trid.trb.org/view/2013/M/1246329

4.7 SUMMARY STATE, MPO, CITY, AND UNIVERSITY DATA (TABLE 4.12)

Table 4.12: Geocoded BLOS data parameter availability at State, MPO, City, and University levels

		State	MPO						City						University		
Category	**Parameter**	**Oregon**	**Metro**	**Mid-Willamette Valley**	**Corvallis Area**	**Central Lane**	**Bend**	**Rogue Valley**	**Portland**	**Salem**	**Corvallis**	**Eugene**	**Bend**	**Ashland & Medford**	**Portland State University**	**Oregon State University**	**University of Oregon**
Bikeway Geometric Design	Facility Type	✓	✓	✓		✓		✓	✓		✓			✓			
	Width of Bicycle Facility	✓		✓													
	Topographic Grade		✓						✓	✓	✓			✓			
Bikeway Environment	Width of MV Buffer (proximity to edge of moving traffic lane)																
	Bicycle marking presence																
	Presence of bicycle signage																
	Presence of trees								✓								
	Presence of bicycle scale lighting																
	Width of Shoulder	✓															
	Presence of Sidewalks	✓	✓						✓								
Roadway Geometric Design	Number of Vehicle Lanes	✓															
	Width of Outside Lane	✓															
	Turning Lane Configuration																
	Physical Median	✓															
	Frequent Curves																
Bicycling Nuisance or Hazard	Presence of On-Street Parking							✓			✓						
	Occupancy of On-Street Parking																
	Conflicting Transit Stop Presence		✓						✓		✓						
	Presence of a Curb								✓								
	Storm Drain Grates																
	Roadside Hazard Presence (Sand, gravel, vegetation, ditches)																
	Restricted Sight Distance																
	Access point density																
	Numerous Driveways																
	Rail Crossings	✓	✓					✓	✓		✓						
	Bike Lane Drop	✓	✓	✓		✓		✓									
	Difficult Transition																
Bikeway Condition	Pavement Condition	✓							✓								
Roadway Traffic	Vehicle Traffic Volume	✓															
	Right Turning Vehicle Volume																
	Vehicle Speed	✓															
	Percentage of Heavy Vehicles																
	Motor Vehicle LOS																
	Bicycle Lane Blockage																
Bikeway Traffic	Average Speed/Acceleration																
	Bicycle Volumes					✓			✓						✓		
	Pedestrian Volume (for multi-use paths)																
Intersection Specific	"No Turn on Red" sign																
	Intersection Type										✓						
	Intersection Quality																

Category	Parameter	Oregon	Metro	Mid-Willamette Valley	Corvallis Area	Central Lane	Bend	Rogue Valley	Portland	Salem	Corvallis	Eugene	Bend	Ashland & Medford	Portland State University	Oregon State University	University of Oregon
		State	MPO						City						University		
	Crossing Distance																
	Number of lanes crossed for cyclist left turn																
	Number of lanes crossed for cyclist right turn																
	Signal Delay																
Built Environment	Activity Density																
	Adjacent Land Use Type		✓	✓					✓		✓			✓			
	Multi-modal or TOD Proximity		✓						✓								
	Bicycle parking presence								✓					✓			
Network	Connectivity	✓	✓			✓		✓	✓		✓			✓			
	Presence of Parallel Facility	✓	✓			✓		✓	✓		✓			✓			
	Intersection Density	✓	✓			✓		✓	✓		✓			✓			
	Road Network Density	✓	✓			✓		✓	✓		✓			✓			
	Bicycle Network Density	✓	✓			✓		✓	✓		✓			✓			
	Permeability/Barrier																
	Stops																
	Route Simplicity																
	Detour																

4.8 OTHER GEOGRAPHIC DATA SOURCES

4.8.1 Google Maps

As discussed in Task 2, Google Maps has a significant inventory of bicycle routes and infrastructure. This inventory was built over several years (with Google officially releasing bicycle route functionality in the U.S. in 2010) through a combination of sources. Google had already had a significant mapping initiative taking inventory of geography across the country, and some of their bicycle routes were added throughout this inventory. Others were added through outreach to local bicycling communities and organizations like the Rails-to-Trails conservancy. Finally, there is also a crowdsourcing element to Google's bicycle route inventory, as users can add un-mapped bicycle routes through Google MapMaker[43], and other users can verify the presence of this bicycle route. More information about Google's bicycle mapping functionality can be found on their Lat-Long blog[44].

Unfortunately, Google's information is proprietary and not available for analysis or reproduction publicly. The massive amount of information available through Google Earth and Street View is also very useful to verify or validate public bicycle facility data

[43] http://www.google.com/mapmaker
[44] http://google-latlong.blogspot.com/2012/08/half-gigameter-of-biking-navigation-in.html

4.8.2 Open Street Maps

Open Street Maps[45] is an open source mapping web application. It functions much like a geographic Wikipedia; as users can modify public maps and the changes are then verified by other users. Maps can be completely customized to display the user's desired information. Users can build their own renditions of Open Street Maps for use in their own web or mobile applications through the web and mobile APIs. The open source nature of Open Street Maps will give ODOT much more freedom for analysis and modification of the bicycle inventory, but some robustness may be sacrificed. TriMet currently uses Open Street Maps as the basis for their Trip Planner[46], which is the first open-source/open-data trip planner utilized by a U.S. transit agency[47].

4.9 DATA GAPS

Although there is a wealth of bicycle data in Oregon, there also some serious gaps and issues. First, many data sources may be in a report, an as-built plan, or a short-term count spreadsheet, but are not available in a comprehensive, geocoded database. Secondly, as described in this chapter, GIS data is not consistent; data fields and definitions change across jurisdictions. Hence, it is not clear if one or more BLOS method can be consistently measured across the state.

As illustrated in Table 4.12, there is a wide range of facility level data not available in a geocoded format. While facility types are generally known and mapped all over the state of Oregon, specific geometric variations in these facility types are not available in the geographic database. For example, bicycle lane widths are not documented in most of the geographic datasets examined herein (the width of a bicycle facility is a primary variable in nearly every BLOS method reviewed in Task 1). ODOT seems to be the only agency that records the numbers of vehicle lanes and AADT along facilities. Pavement condition is not documented in most of the datasets examined at the local or MPO level. While many agencies (at State, MPO, and City levels) count vehicles in some capacity (short-term or continuous), most of these counts are not immediately available in a geocoded format. The same can be said for bicycle counting programs. Volume data access and consistency statewide would be invaluable to this and other research efforts. Bicycle demand data and counts can be useful to validate or compare against smartphone route data.

[45] http://www.openstreetmap.org/about
[46] http://ride.trimet.org/#/
[47] http://trimet.org/howtoride/maptripplanner.htm

5.0 APPLICATION DEVELOPMENT

The development of the ORcycle smartphone application was the first concrete outcome of this research. The application was developed to collect cyclists' user, trip, and safety data across the State of Oregon. This section reviews the development process of the ORcycle smartphone application and the different ORcycle sections and questionnaires.

5.1 ORCYCLE SURVEY TOOL DESIGN

Development of the applications (Android and iOS) took place primarily between May 2014 and April 2015. The U.S. smartphone market is as of late 2014[48] dominated by Android with a 53% market share and iOS comprising 42% of the market; other companies such as Microsoft and Blackberry hold the remainder market share. The original research contract SPR 768 indicated that the pilot application and data collection would be done only utilizing an Android platform. *The research team exceeded the contractual requirements by also developing an iOS version of the app*. With the addition of an iOS version a 95% of the smartphone market can be reached with the ORcycle application.

ORcycle was developed for Android using Eclipse[49], an open-source Android Integrated Development Environment (IDE). Android software is written primarily in the Java coding language. (Figure 5.1) The Android version of ORcycle was built off of the open-source Android version of Cycle Atlanta, which was built off of CycleTracks. The application was re-branded as ORcycle, and then many features were modified and/or added. The application was tested numerous times on different Android devices throughout the development and debugging process. ORcycle was developed for iOS using XCode, Apple's proprietary IDE. ORcycle was written primarily in the Objective-C coding language. ORcycle was built off of the iOS version (Figure 5.2) of RenoTracks, which was built off of the iOS version of Cycle Atlanta, which was built off of the iOS version of CycleTracks. The iOS application was re-branded as ORcycle and then many features were modified and/or added.

Many unique features were added to ORcycle. These features include a unique focus on cyclists' type and riding preferences as well as on comfort and safety. New questionnaires were added as well as other user friendly features such as feedback messages, reminders, and alarms.

[48] http://www.statista.com/statistics/266572/market-share-held-by-smartphone-platforms-in-the-united-states/
[49] Eclipse website: https://www.eclipse.org/

Figure 5.1: Home Screen of the Android Version of ORcycle

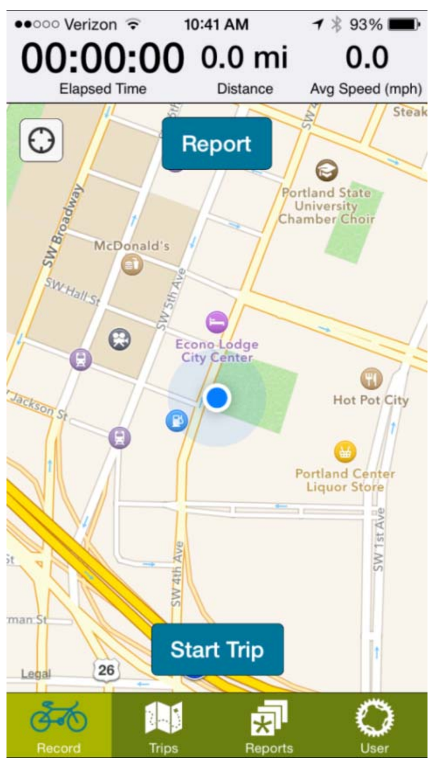
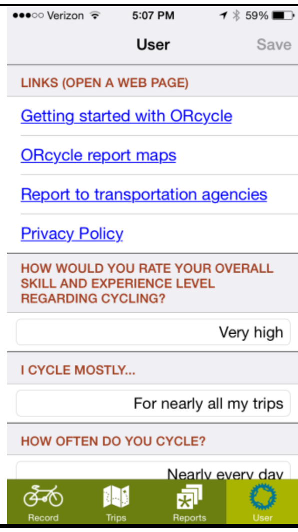
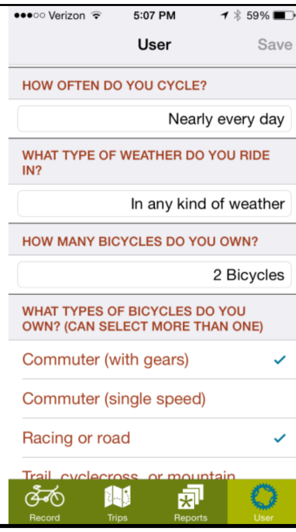
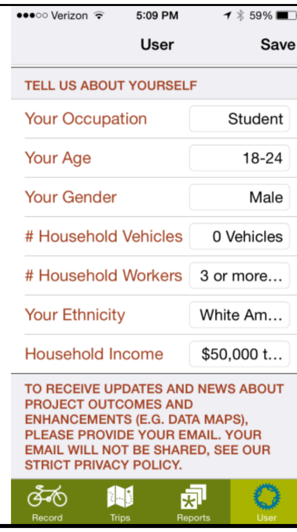


Figure 5.2: Home screen of the iOS version of ORcycle

5.2 USER DATA COLLECTION

User group questions were designed to control for differences in cyclists' demographics and riding preferences. The user questions were asked through the screens presented in **Error! Reference source not found.**. The user questions utilized in the final version of the application, released in March 2015, are outlined below. The questions are broken up into two groups: (1) questions about riders' demographics and (2) questions about a riders' biking attitude and cyclist type. All user group questions are optional.
An important criterion when designing user questions was to limit the number of user questions as much as possible (seven) to reduce user burden. Pilot testing feedback indicated user uneasiness and a reduction in the response rate when the number of questions exceeded seven.

Table 5.1: User Screens (iOS version)

<table>
<tr><th>Screen #</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>iOS</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

5.2.1 Demographic Information

Demographic indicators are often significant covariates with cycling travel behavior (see literature review). The demographic data collected by ORcycle includes age, ethnicity, gender, household income, occupation, number of household workers, and number of household vehicles.

Age was considered in all of the previous CycleTracks-derived smartphone applications and is included in most travel surveys. Cyclists and smartphone users are both generally on the younger end of the age spectrum; it is important to control for this factor when making inferences from the application data. The age group stratification used in ORcycle is outlined in Table 5.2.

.

Table 5.2: Age Group Responses

Age Category
No data
Less than 18
18-24
25-34
35-44
45-54
55-64
65+

Ethnicity was another major demographic variable to control for and was considered in several of the cycling apps. Cyclists are generally less diverse than the population at large *(Pucher et al. 2011; Pucher et al. 2010; Dill and Voros 2007)*. The ethnicity selection categories used in ORcycle are outlined in Table 5.3.

Table 5.3: Ethnicity group responses

Ethnicity Category
No data
African American
Asian American
Hispanic
Native American
White American
Other

Bicycling mode share differs considerably by gender, with more males cycling than females on average at this time. The proposed categorization schema for gender selection is outlined in Table 5.4.

Table 5.4: Gender group responses

Gender Category
No data
Female
Male
Other

Middle to high income groups tend to be more likely to commute by bicycle within the U.S. (Pucher et al. 2011). The income category selection is different from previous applications because it was designed to match the Oregon Household Activity Survey (OHAS) categories. The proposed categorization schema for income range selection is listed in Table 5.5.

Table 5.5: Income group responses

Income Category
No data
Less than $14,999
$15,000 to $24,999
$25,000 to $34,999
$35,000 to $49,999
$50,000 to $74,999
$75,000 to $99,999
$100,000 to $149,999
$150,000 or more

Occupation may influence route choice and this variable is useful to group cyclists into different groups. The available choices for this question are outlined in Table 5.6.

Table 5.6: Occupation responses

Occupation Category
No data
Employed
Student
Retired
Homemaker
Other

Household size is a typical question in household travel surveys because it is an important predictor of household trips. Instead of assessing household size, it was decided in conjunction with the ODOT TAC, that asking for the number of household workers and the number of household vehicles would be more pertinent. With ORcycle it is possible to calculate a vehicle/worker ratio per household to estimate accessibility to private motorized vehicles. The proposed categorization schema for household workers is listed in Table 5.7; the proposed categorization schema for number of household vehicles is listed in Table 5.8.

Table 5.7: Household workers responses

Household Workers Category
No data
0 Workers
1 Worker
2 Workers
3 Workers or more

Table 5.8: Household vehicles responses

Household Vehicles Category
No data
0 vehicles
1 vehicle
2 vehicles
3 vehicles or more

5.2.2 Cyclist Typology

Six questions are asked to evaluate the "type" of cyclist using the application. The number of bicycles the rider owns may indicate a cyclist's proclivity towards bicycling. The available choices for this question are given in Table 5.9.

Table 5.9: Number of bicycles owned

Income Category
No data
0 bicycles
1 bicycle
2 bicycles
3 bicycles
4 or more bicycles

Knowing a user's bicycle type(s) may reveal information about relationships between facility preferences, route choices, and user characteristics. This question was asked as the following: "What types of bicycles do you own?" (can select more than one) and the available responses are listed in Table 5.10.

Table 5.10: Bicycle Type (select multiple)

Bicycle Type Response
No data
Commuter (with gears)
Commuter (single speed)
Racing or road
Cycle Cross or mountain
Cargo Bike
Recumbent
Other

A cyclist's self-reported general comfort/ability level with riding a bicycle can reveal a baseline level of comfort which must be taken into account when analyzing comfort/stress level on specific routes and facilities. A Likert-type scale was used and the question was asked as the following: “How would you rate your overall skill and experience level regarding cycling?” and the available responses for this question are outlined in Table 5.11.

Table 5.11: Cycling Ability

General Cycling Comfort Category
No data
Very Low
Low
Average
High
Very High

Cycling prominence as a mode of transportation is asked indirectly through the following question: “I cycle mostly … ” and the available responses for this question are outlined in Table 5.12.

Table 5.12: Cycling Prominence

Cycling Prominence
No data
For nearly all my trips
To and from work
For recreation and/or exercise
For shopping, errands, or visiting friends
Mainly to and from work, but occasionally for exercise, shopping, etc.
Other

Tolerance for adverse weather is useful to group cyclists in Oregon. This question is asked as the following: “What type of weather do you ride in?” and the available responses for this item are outlined in Table 5.13.

Table 5.13: Weather Tolerance

Weather Tolerance
no data
In any kind of weather
When it does not rain
Usually warm and dry weather
Only with warm and dry weather

Cycling frequency impacts facility preferences and route choice *(Teschke and Winters 2013)*. The cycling frequency question is asked as the following: “How often do you cycle?” The available responses for this question are given in Table 5.14.

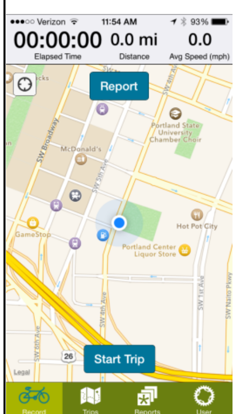
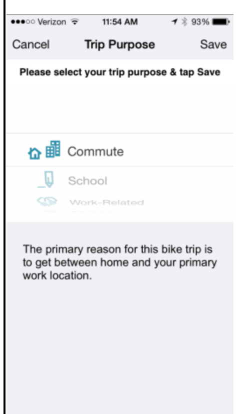
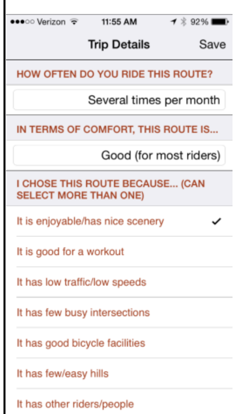
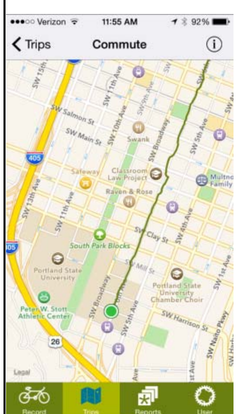
Table 5.14: Cycling Frequency

Cycling Frequency Category
no data
A few times per year
A few times per month
A few times per week
Nearly every day

5.3 TRIP DATA COLLECTION

Obtaining the time-space trajectories of cyclists utilizing the application was one of the primary objectives of the application. Knowing empirically when and where cyclists chose to ride provides a wealth of revealed preference information about cyclist preferences. These time-space trajectories were obtained using the Android and iPhone devices' built-in GPS units. Within the application, a user can start recording GPS coordinates by pressing the "Start Trip" button on the "Record" screen. (Table 5.15) This initializes the GPS coordinate recording, which continues until the user indicates that they have finished traveling and/or recording GPS coordinates. For the remainder of the document, this GPS coordinate trajectory will be referred to as a "Trip".

Table 5.15: Trip Screens

Screen #	1	2	3	4
iOS				
Description	Users can begin recording a trip by pushing "start trip".	Users can then respond to trip questions including trip purpose, route frequency, and route comfort.		Trips can then be reviewed with summary statistics and saved responses.

Five questions are asked after each trip to gain more information about trip purpose, route frequency, route comfort, and route stressors. Following the implementation of prior applications, trip purpose can be selected after a trip is completed. The available trip purpose categories, descriptions, and corresponding icons are outlined in Table 5.16.

Table 5.16: Trip Purpose (Question 20) Responses, Descriptions, and Icons (select one)

Trip Purpose	Description	Visual Icon
Commute	This bike trip was primarily to get between home and your main workplace.	
School	This bike trip was primarily to go to or from school or college.	
Work related	This bike trip was primarily to go to or from a business related meeting, function, or work-related errand for your job.	
Exercise	This bike trip was primarily for exercise, or biking for the sake of biking.	
Social or Entertainment	This bike trip was primarily for going to or from a social activity, e.g. at a friend's house, the park, a restaurant, the movies.	
Shopping or Errands	This bike trip was primarily to attend to personal business such as buying groceries, banking, a doctor visit, going to the gym, etc.	
Transport Access	The primary reason for this bike trip was to access public transit or some other vehicle (private vehicle, car share, etc.)	
Other	If none of the other reasons applied to this trip, you can enter comments below to tell us more.	

User familiarity with a route may have an effect on their perception of the route. A route frequency question is asked as the following: “How often do you ride this route?” and the available answers for this question are given in Table 5.17.

Table 5.17: Route Frequency (Question 19) Responses (select one)

Route Comfort Response
No data
Several times per week
Several times per month
Several times per year
Once per year or less
First time ever

Previous apps do not include any trip question besides trip purpose. However, self-reported route choice characteristics can be very useful to model route choice behavior. This question is asked as the following: “I chose this route because … (can select more than one)” and the available responses are listed in Table 5.18.

Table 5.18: Route choice preferences (Question 21) responses (select multiple)

Route Preferences Response
No data
It is direct/fast
It has good bicycle facilities
It is enjoyable/has nice scenery
It is good for a workout
It has low traffic/low speeds
It has few intersections
It has few/easy hills
It has other riders/people (I'm not alone)
I do not know/have another route
I found on my phone/online
Other (indicate in comments)

The route comfort question was design to match the Level of Traffic Stress scale and description. This question has never been included in other applications and is asked as the following: "In terms of comfort, this route is…" and the available responses are given in Table 5.19.

Table 5.19: Route Comfort (Question 22) Responses (select one)

Route Comfort Response
No data
Very bad (unacceptable for most riders)
Bad (only for confident riders)
Average
Good (for most riders)
Very Good (even for families/children)

Following the theme of the previous question, a question asks what the causes of concern or stress are. This question is asked as the following: "Along this route, you are concerned about conflicts/crashes with… (can select more than one)" and the available responses are listed in Table 5.20.

Table 5.20: Route stressors (Question 27) responses (select multiple)

Route Stressors Response
Not concerned
Auto traffic
Large commercial vehicles (trucks)
Public transport (buses, light rail, streetcar)
Parked vehicles (being doored)
Other cyclists
Pedestrians
Other

The final data question is not mandatory and simply asks for additional details and there is a box to write a comment.

5.4 CRASH AND SAFETY ISSUE REPORTS

The ability to record “issues” and “assets” (referred to as “notes”) was one of the most significant improvements to Cycle Atlanta. This functionality combines the uses of a bicycle trip tracking application like CycleTracks with the infrastructure crowdsourcing functionality of applications like Citizens Connect and PDX Reporter. In ORcycle there is no asset recording functionality but there is more focus on safety and crash data which has a significant value given that many bicycle crashes are underreported. In ORcycle these data objects are called “Reports” instead of “Notes”.

There are two types of reports: (1) crash or near-crash events and (2) location specific infrastructure/safety issues. In both cases a cyclist can input the location of report objects, which can be submitted as the current phone location or a custom location selected on a dynamic map. Reports were also uploaded with a date, which could either be the current date or a custom-selected date.

5.4.1 Crash or near-miss

Crash event reports were submitted using the screens shown in Table 5.21. Crash event reports asked four mandatory questions: (1) crash severity, (2) vehicle or object related to event, (3) crash event actions, and (4) crash event reasons. The user must also indicate the relative severity of their crash event. The question was asked as the following: “Severity of the crash event: (choose one)” and the available answers for this question are given in Table 5.22.

Table 5.21: Crash Report Screens

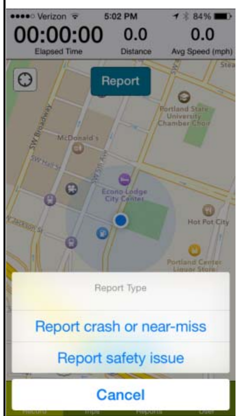
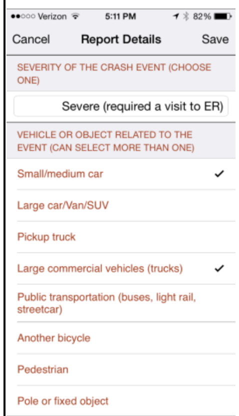
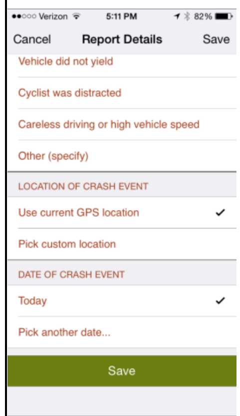
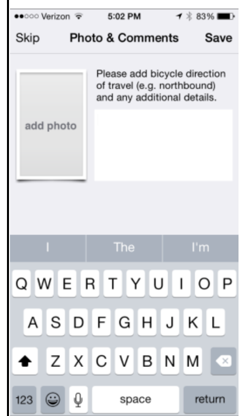
Screen #	1	2	3	4
iOS				

Table 5.22: Crash event severity responses (select one)

Severity Category	Report Icon
Major injuries (required hospitalization)	
Severe (required a visit to ER)	
Minor injury (no visit to ER)	
Property damage only (bicycle damaged but no personal injuries)	
Near-miss (no damage or injury)	

There is a question about the vehicle or physical object involved in the crash or near-miss. This question was asked as the following: “Vehicle or object related to the event… (can select more than one)” and the available answers for this question are given in Table 5.23. The user must also report what particular traffic movements or actions led to the crash event. The corresponding question was asked as the following: “Actions related to the event… (can select more than one) and the available answers for this question are given in Table 5.24.

Table 5.23: Vehicle or object responses (select multiple)

Vehicle or object category
Small/medium car
Large car/Van/SUV
Pickup truck
Large commercial vehicles (trucks)
Public transport (buses, light rail, streetcar)
Another bicycle
Pedestrian
Pole or fixed object
Cyclist fell (or almost fell)
Other

Table 5.24: Crash event actions responses (select multiple)

Crash event actions
Right-turning vehicle
Left-turning vehicle
Parking or backing up vehicle
Person exiting a vehicle
Cyclist changed lane or direction of travel
Vehicle changed lane or direction of travel
Cyclist did not stop
Driver did not stop
Cyclist lost control of the bike
Other

The user must also report what environmental, traffic, or personal conditions may have contributed to the crash event. The corresponding question was asked as the following: “What contributed to the event? (can select more than one)” and the available answers for this question are given in Table 5.25.

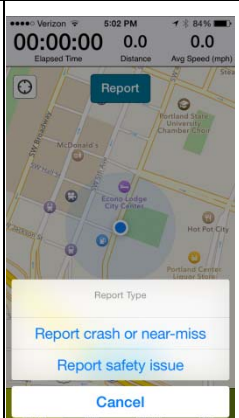
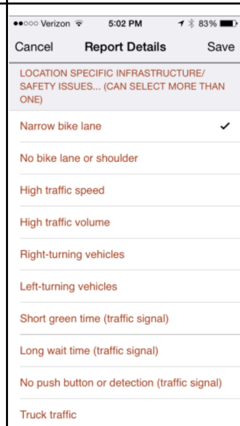
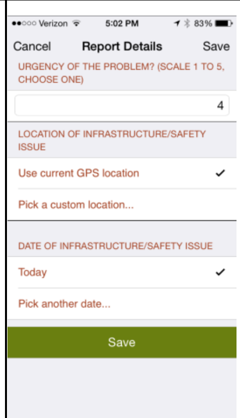
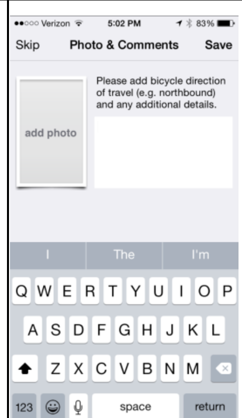
Table 5.25: Crash event reasons responses (select multiple)

Crash event reasons
Debris or pavement quality
Poor lighting or visibility
Cyclist was outside the bike lane or area
Vehicle entered the bike lane or area
Cyclist did not follow stop sign or red light
Vehicle did not follow stop sign or red light
Cyclist did not yield
Vehicle did not yield
Cyclist was distracted
Careless driving or high vehicle speed
Other

5.4.2 Infrastructure issues

Infrastructure reports were submitted using the screens shown in Table 5.26; for infrastructure reports there are two mandatory questions: (1) issue type and (2) issue urgency.

Table 5.26: Issue Report Screens

<table>
<tr><td>Screen #</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>iOS</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

The first question asked when a user reported a “safety/infrastructure issue” was a description of the issue type. This question was asked as the following: “Location specific infrastructure/ safety issues… (can select more than one)” and the available “issue types” for documentation are given in Table 5.27.

Table 5.27: Issue Type responses (select multiple)

Issue Type
Narrow Bike Lane
No bike lane or separation
High vehicle speeds
High traffic volumes
Right/left turning vehicles
Traffic signal timing
No traffic signal detection
Truck traffic
Bus traffic/stop
Parked vehicles
Pavement condition
Other

The user was also asked to indicate the urgency level of the issue; the user must indicate the relative urgency of the issue on a scale of 1 to 5. The question was asked as the following: "Urgency of the problem: (choose one)" and the available answers for this question are given in Table 5.28.

Table 5.28: Issue urgency responses (select one)

Severity Category	Report Icon
1 (not urgent)	
2	
3 (somewhat urgent)	
4	
5 (urgent)	

6.0 DATA ANALYSIS

This section presents a description of the data collected during the pilot study. Descriptive statistics associated to user, trip, and report data are presented first. Potential sample biases are also analyzed. The section ends exploring the suitability of ORcycle data for studies focusing on LTS and comfort levels. Data cleaning and processing took place in MS Excel and in the R Project for Statistical Computing environment.

6.1 USER CHARACTERISTICS

Users were asked several optional questions that they could answer upon first opening the application or anytime thereafter. The questions consisted of two main groups: one group targeted bicycling attitudes and the second group gathered demographic characteristics.

Upon downloading ORcycle, each installation was given a unique “user” identity. Associated with that user identity were the responses to all the user-related survey questions explored below. The user sample considered herein included users that were “created” (i.e. downloaded the application and uploaded at least one trip or report) between the application release on November 1st, 2014 and March 31st, 2015. User creation rates and the cumulative number of users created over the study period are graphed in Figure 6.1 and Figure 6.2. There was an initial surge in user participation just after the application release with 226 users by December 1st, but the number of new users slowed to an average rate of approximately 1.4 users per day within a month of the release. There were a total of 381 users in the sample considered herein.

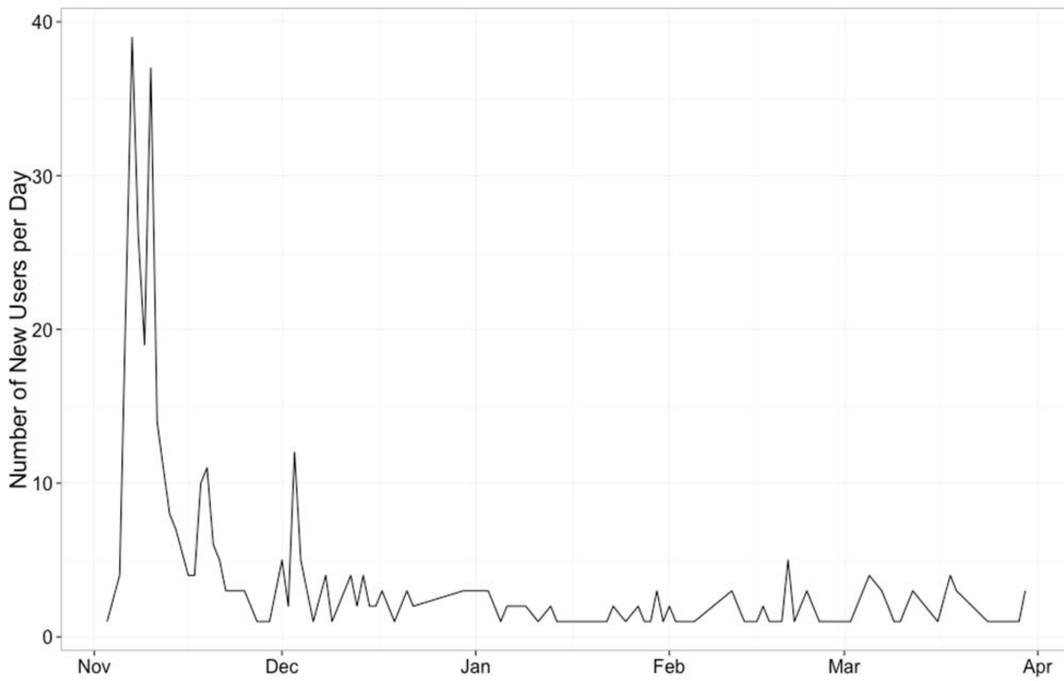


Figure 6.1: Users created per day during study period

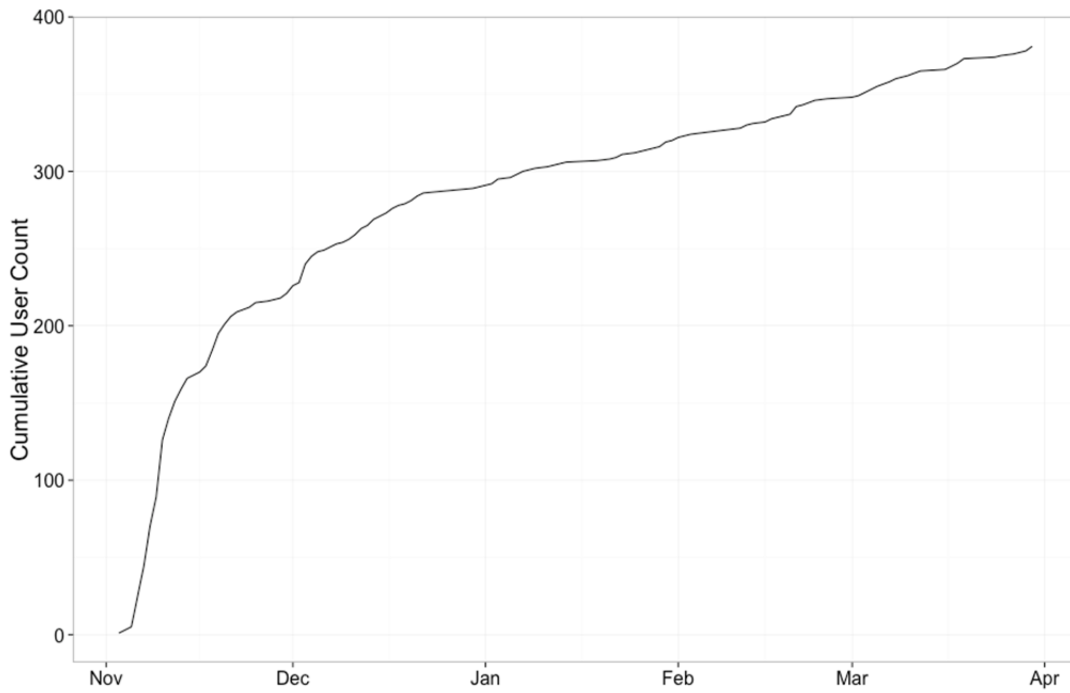


Figure 6.2: Cumulative user count over study period

6.1.1 Smartphone platform

Users could download and operate the ORcycle application for either iOS (e.g. iPhone) or Android (e.g. Samsung Galaxy, Google Nexus) operating system platforms. Figure 6.3 indicates that the majority of users (67%) used ORcycle on Android devices. The U.S. smartphone market is (as of late 2014[50]) marginally dominated by Android (53%), with iOS comprising 42% of the market and competitors like Microsoft and Blackberry holding the remainder of smartphone users. Among the initial sample of users of ORcycle, the proportion of Android users was higher than the market average.

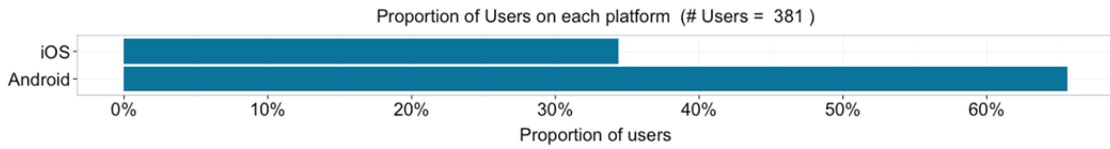


Figure 6.3: User distribution by platform

6.1.2 Age

Age category distribution within the sample is illustrated in Figure 6.4. Within the sample, the majority of users (52%) are between 25 and 44. There was a negligible amount of under-18 users and 17% of users chose not to provide information about their age.

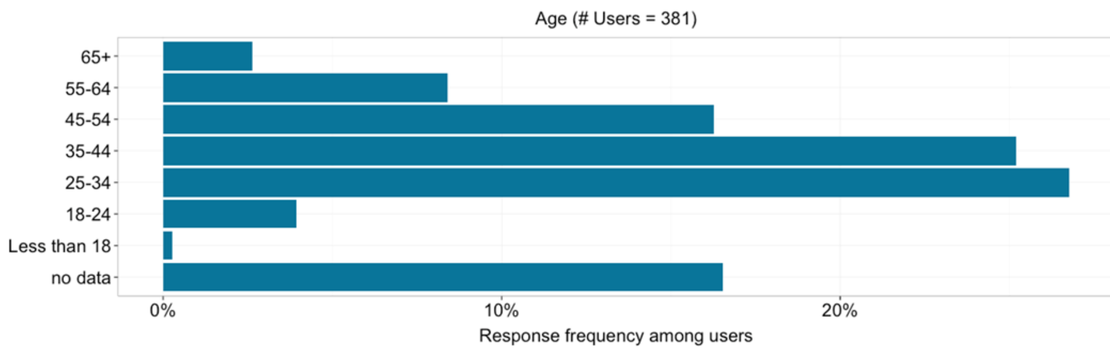


Figure 6.4: Age distribution of users

6.1.3 Gender

Gender distribution among the user sample is illustrated in Figure 6.5. 68% of users identified as males and 15% as females; 17% of users declined to provide information about their gender group or chose “other”.

[50] http://www.statista.com/statistics/266572/market-share-held-by-smartphone-platforms-in-the-united-states/

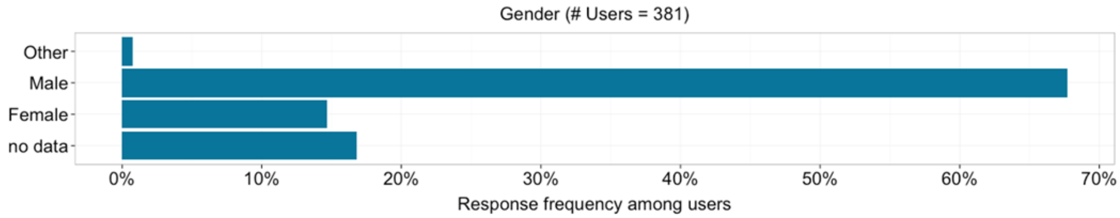


Figure 6.5: Gender distribution among users

6.1.4 Ethnicity

The ethnicity distribution among the user sample is illustrated in Figure 6.6. 70% of users identified as "White American", with less than 5% for each of the other available ethnicity categories; 20% of the users declined to provide information about their ethnicity. As a reference Portland's white population share is 76% in 2010[51] and Oregon's share of white population is 84% in 2010. Though cycling studies are typically biased towards white demographics (see literature review), the proportion of ORcycle users that are white seems to be in order with the ethnicity makeup of Portland and Oregon.

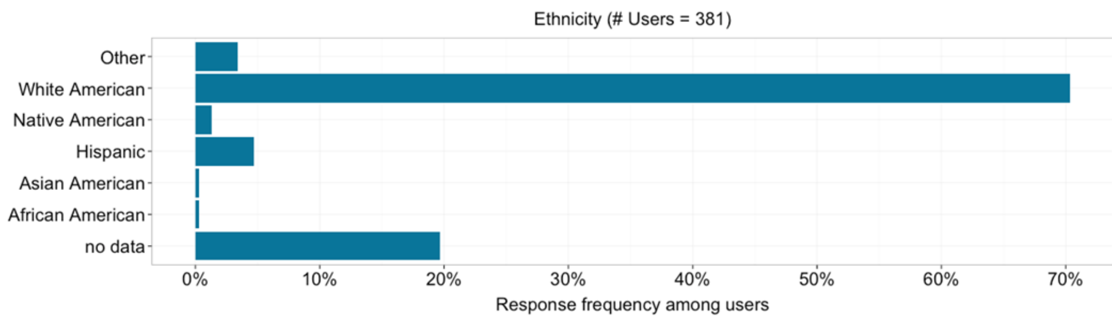


Figure 6.6: Ethnicity distribution among users

6.1.5 Occupation

The occupation distribution among the user sample is illustrated in Figure 6.7 where 68% of users indicated that they were employed and 8% of users indicated that they were students; 18% of users declined to provide information about their occupation.

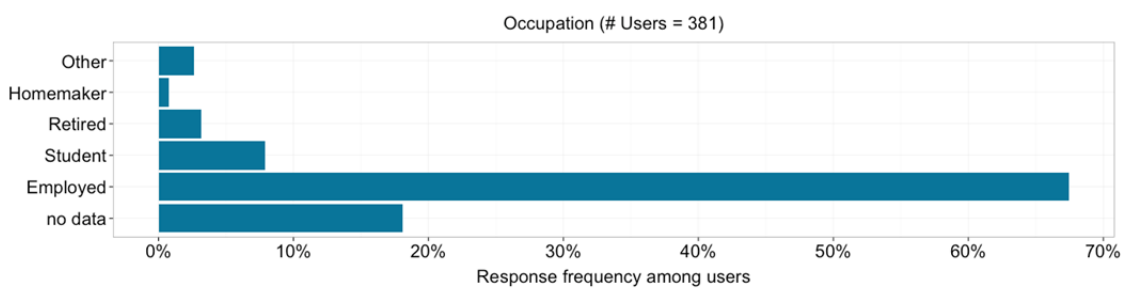


Figure 6.7: Occupation distribution among users

51 http://quickfacts.census.gov/qfd/states/41/4159000.html

6.1.6 Household Income

The household income group distribution among the user sample is illustrated in Figure 6.8. The majority of users fell into the middle to high-income categories; 25% of users declined to provide information about their household income.

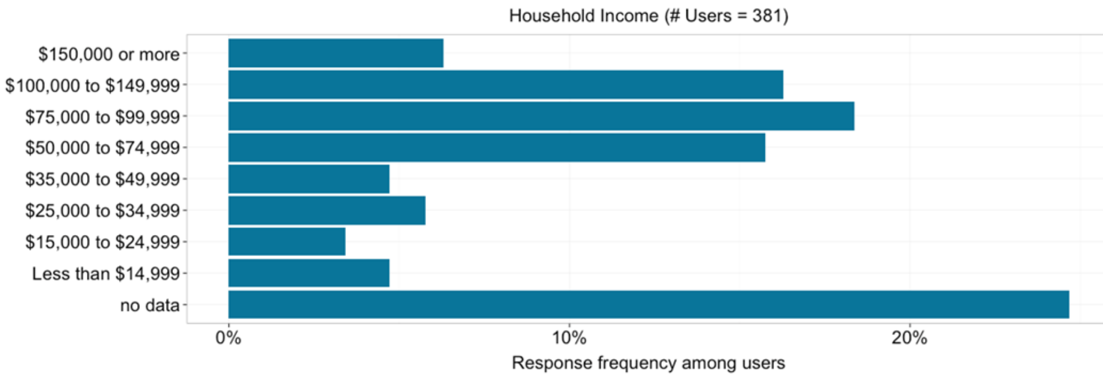


Figure 6.8: Household income distribution among users

6.1.7 Household Workers

The distribution of number of workers per household is illustrated in Figure 6.9. The majority of users (72%) indicated that they lived in one or two worker households and 18% of users declined to provide information about the number of workers in their households.

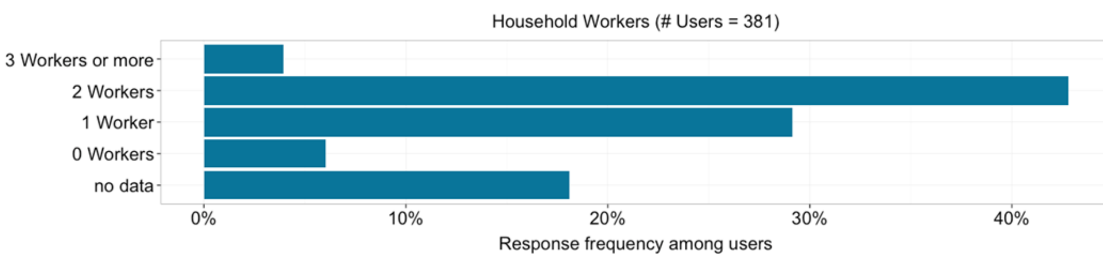


Figure 6.9: Household workers distribution among users

6.1.8 Household Vehicles

The distribution of the number of vehicles per household vehicle is illustrated in Figure 6.10. The majority of users (64%) indicated that they lived in a one-vehicle or two-vehicle households. The proportion of users that indicated that they lived in zero vehicle households was 12% and 16% of the sample declined to provide information about the number of vehicles owned in their household.

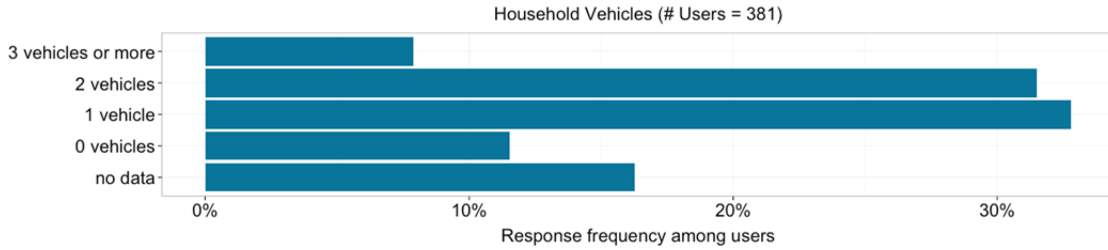


Figure 6.10: Household vehicles distribution among users

6.1.9 Household Workers to Vehicles Ratio

The number of household vehicles was divided by the number of household workers to calculate a vehicles/workers ratio. This ratio could be used as an indicator of vehicle accessibility within a household. The mean vehicles/workers ratio was close to one but there were 104 users, roughly one third of the sample, with ratios below one. The distribution of the vehicles/workers ratio is summarized in Table 6.1 and Figure 6.11.

Table 6.1: Vehicles/Workers Distribution Summary

Statistic	N	Mean	St. Dev.	Min	Max
Vehicles/Workers Ratio	314	1.054	0.579	0.250	4.000

Figure 6.11: Vehicles/workers ratio distribution among users

6.1.10 Number of Bicycles

Users were asked to indicate the number of bicycles that they personally owned and the distribution is illustrated in Figure 6.12. The distribution is fairly evenly spread with the exception of those who owned zero bicycles; 15% of users declined to provide this information.

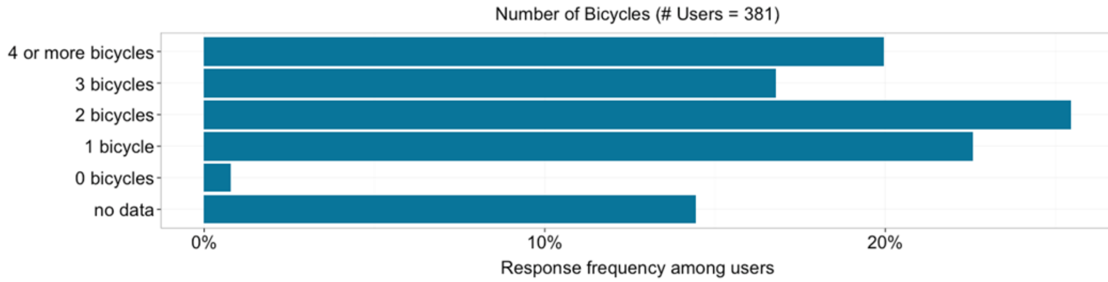


Figure 6.12: Number of bicycles among users

6.1.11 Bicycle Types

Users were asked to indicate the type of bicycles that they owned with the ability to select multiple choices. The bicycle type distribution among the user sample is illustrated in Figure 6.13. Nearly 61% of the sample indicated they owned a commuter bicycle (with gears), 39% of the sample indicated they owned a racing/road bike and/or a trail/cyclocross/mountain bike, 18% of the sample indicated they owned other types of bicycles not available within the selection set, and 15% of the sample declined to provide any information about their bicycle types.

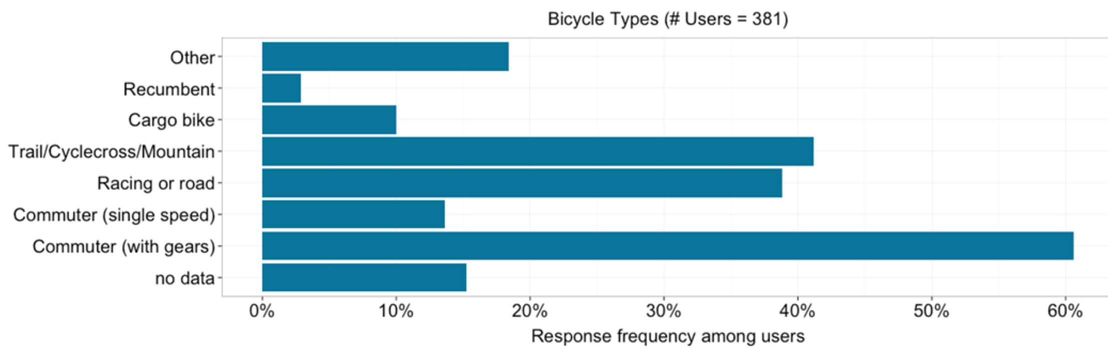


Figure 6.13: Bicycle type distribution among users

6.1.12 Cycling Frequency

The cycling frequency distribution among the user sample is illustrated in Figure 6.14. Roughly 50% of users indicated that they bike "nearly every day", 22% of users indicated that they biked "a few times per week", and 15% of users declined to provide information about their cycling frequency.

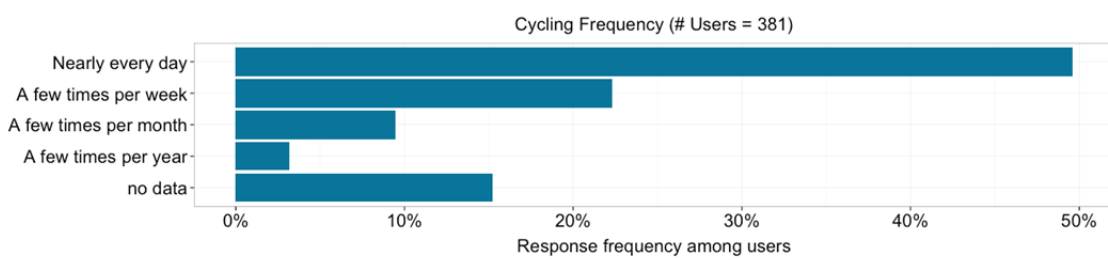


Figure 6.14: Cycling frequency distribution among users

6.1.13 Preferred Cycling Weather

The cycling weather distribution among the user sample is illustrated in Figure 6.15. The majority of users (67%) indicated that they would bicycle "In any kind of weather and 14% of users declined to provide information about their preferred cycling weather.

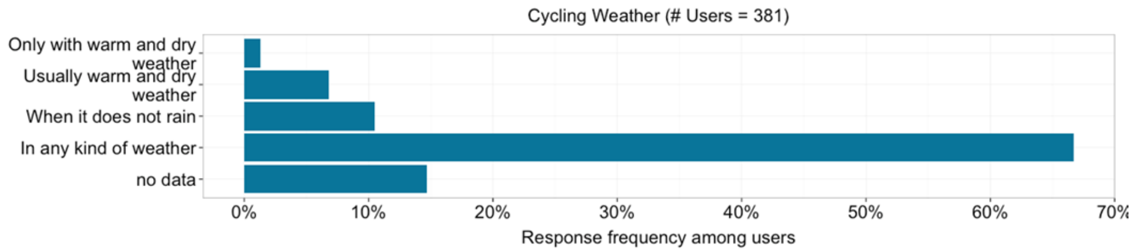


Figure 6.15: Preferred cycling weather distribution among users

6.1.14 Cycling Ability

The cycling ability distribution among the user sample is illustrated in Figure 6.16. Almost one-third of the of users (33%) indicated they had "Very High" cycling abilities, 32% indicated they had "High" cycling abilities, less than 2% of users indicated they had "Low" or "Very Low" cycling abilities, and 17% declined to provide information about their cycling ability.

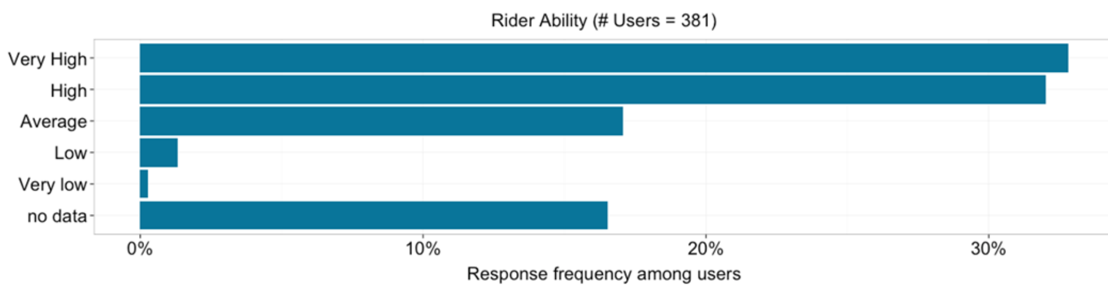


Figure 6.16: Cycling ability distribution among users

6.1.15 Cycling Prominence

The response distribution is illustrated in Figure 6.17. Nearly 28% of users indicated that they rode a bicycle "For nearly all my trips", 19% of users indicated that they rode a bicycle "To and from work", 16% of the users indicated that they rode mainly for recreation or exercise, and 15% of users declined to answer this question.

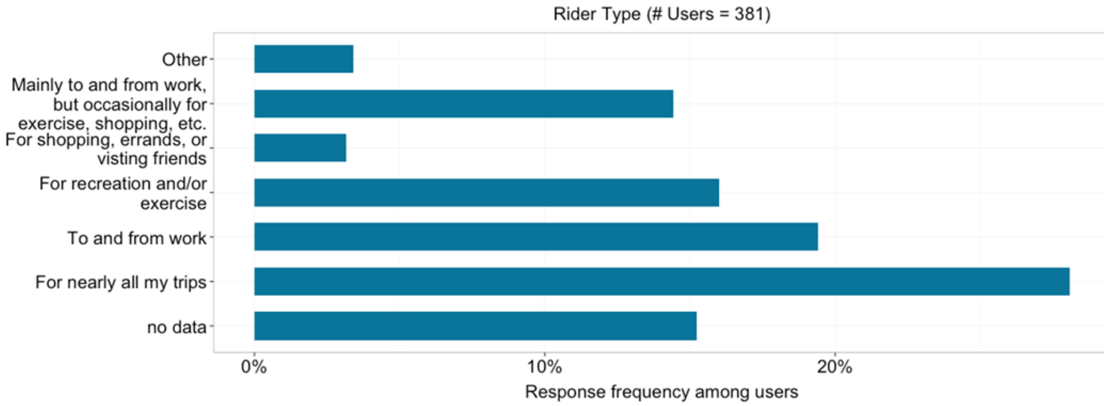


Figure 6.17: Rider type distribution among users

6.2 USER SAMPLE BIAS

ORcycle was promoted shortly after its release on November 3rd 2014 through internet and e-mail campaigns led by ODOT TAC members and the project PI. Due to project time constraints, only users created and trips/reports recorded up to March 31st, 2015 were analyzed for this report. The analysis herein only applies to this specific sample of users, trips, and reports.

Since the promotion for the data collection effort took place mostly in November (Oregon's rainy and cold season), it is not surprising that most of the users feel comfortable riding in any kind of weather or were frequent riders with high self-reported cycling skill levels. To gauge potential sample bias the ORcycle sample was compared with the Oregon Household Activity Survey (OHAS) sample. The OHAS sample is assumed to be more representative of the Oregon cycling and general population due to a more rigorous sampling methodology (telephone based instead of smartphone based); both the entire OHAS sample and the subsample of bicycle commuters were compared against ORcycle sample. The results of the chi-square statistical tests comparing the samples are presented below in Table 6.2.

Table 6.2: Chi-square testing of user sample bias

Demographic Characteristic	ORcycle vs. OHAS Bike Commuters			ORcycle vs. OHAS Entire Sample		
	Chi-Square	DF	Significance	Chi-Square	DF	Significance
Age	89.4	6	p<0.001	592	6	p<0.001
Gender	28.4	1	p<0.001	157	1	p<0.001
Ethnicity	33.3	5	p<0.001	47.5	5	p<0.001
Household Income	15.5	7	p<0.05	57.6	7	p<0.001
Household Workers	61.4	3	p<0.001	67.9	3	p<0.001
Household Vehicles	39.5	3	p<0.001	123	3	p<0.001

All of the tests resulted in statistically significant differences, though some characteristics had greater differences than others (as gauged by the chi-square statistic). However, a statistically significant differences not always mean a practical significance since the percentage figures are very small in some cases; see Tables 6.3 through Table 6.8 in this section for a more detailed comparison between OHAS, OHAS bicycle, and ORcycle samples regarding age, gender, ethnicity, income, number of vehicles, and number of bicycles per household.

The ORcycle sample is more similar to the OHAS bike commuter sample than to the entire OHAS sample; this is expected and indicates that ORcycle was reaching Oregon's cycling population to some degree. In some cases, for example for race, the ORcycle sample is more diverse than the bicycling population shares captured in OHAS.

Table 6.3: Age sample comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	45,695	802	339
< 18	20.0 %	1.6 %	0.3 %
18-24	4.0 %	5.9 %	4.7 %
25-34	6.4 %	12.5 %	32.1 %
35-44	10.8 %	23.8 %	30.2 %
45-54	16.5 %	29.8 %	19.5 %
55-64	21.1 %	23.6 %	10.1 %
65+	21.2 %	2.9 %	3.1 %

Table 6.4: Gender sample comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	46,368	818	335
Female	52.2 %	33.7 %	17.8 %
Male	47.8 %	66.3 %	82.2 %

Table 6.5: Ethnicity sample comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	19,526	711	332
African American	0.5%	0.0%	0.3%
Asian American	1.0%	2.0%	0.3%
Hispanic	2.8%	2.4%	5.9%
Native American	0.9%	0.3%	1.6%
White American	93.8%	94.4%	87.6%
Other	1.0%	1.0%	4.2%

Table 6.6: Household Income sample comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	18,637	690	316
$0-$14,999	6.7%	2.9%	6.3%
$15,000-$24,999	10.4%	5.5%	4.5%
$25,000-$34,999	9.8%	7.4%	7.7%
$35,000-$49,999	14.2%	10.3%	6.6%
$50,000-$74,999	23.1%	25.9%	20.6%
$75,000-$99,999	17.2%	23.3%	24.0%
$100,000-$149,999	12.8%	17.0%	22.0%
$150,000 or more	5.8%	7.7%	8.4%

Table 6.7: Household number of vehicles comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	19,932	736	339
0 Vehicles	4.3 %	4.9 %	13.8 %
1 Vehicles	27.8 %	34.6 %	39.2 %
2 Vehicles	40.5 %	41.4 %	37.6 %
3 or more Vehicles	27.3 %	19 %	9.4 %

Table 6.8: Household number of workers comparison

Sample	OHAS	OHAS Bicycle Commuters	ORcycle
N	19,932	736	334
0 Workers	23.9 %	0.4 %	7.4 %
1 Worker	36.9 %	27.3 %	35.6 %
2 Workers	34.5 %	61.3 %	52.2 %
3 or more Workers	4.7 %	11 %	4.8 %

6.3 TRIP DATA

Trip data came in two distinct types: the GPS coordinate trace of the trip and the responses to the post-trip survey questions. All the trips considered herein were logged between the application release on November 1st, 2014 and March 31st, 2015. The trip recording rate and the cumulative number of trips recorded are graphed in Figure 6.18 and Figure 6.19. As with user creation, there was an initial surge in trip recording following the release and promotion of the app. Trip recording activity leveled off to a slower nearly constant rate of 5.6 trips per day. A total of 780 trips are considered in the following sample description.

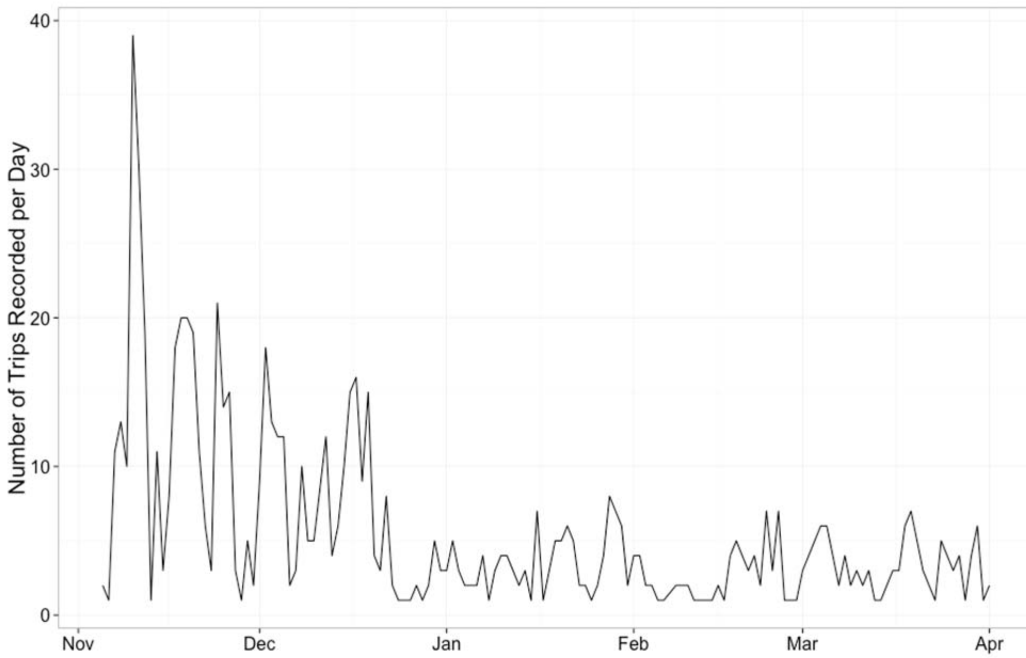


Figure 6.18: Rate of trip recording over study period

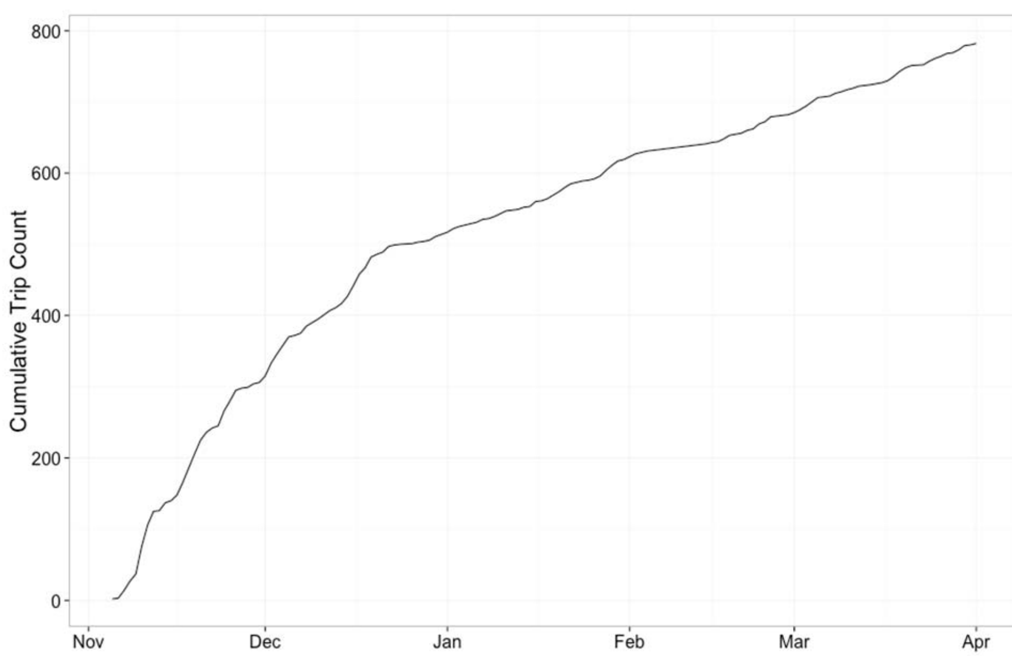


Figure 6.19: Cumulative number of trips recorded over study period

6.3.1 Trip Purpose

Users were asked to indicate for each trip their primary trip purpose. This question was mandatory upon recording a trip. The trip purpose distribution among the trip sample is illustrated in Figure 6.20. Almost 55% of trips were indicated to be commuting trips with the next highest category being "shopping/errands" at 14%.

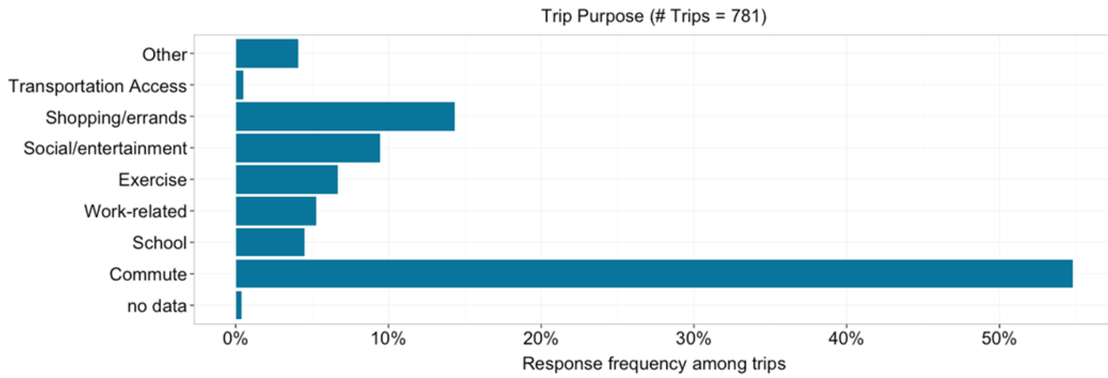


Figure 6.20: Trip Purpose Distribution among Trips

6.3.2 Route Frequency

This route frequency question was mandatory upon the recording of a trip. The route frequency distribution among the trip sample is illustrated in Figure 6.21. Almost half of the trips, 47% of the routes, were indicated as being ridden "several times per week" by the user. Other trips were indicated to be ridden several times per month (22%) and several times per year (18%).

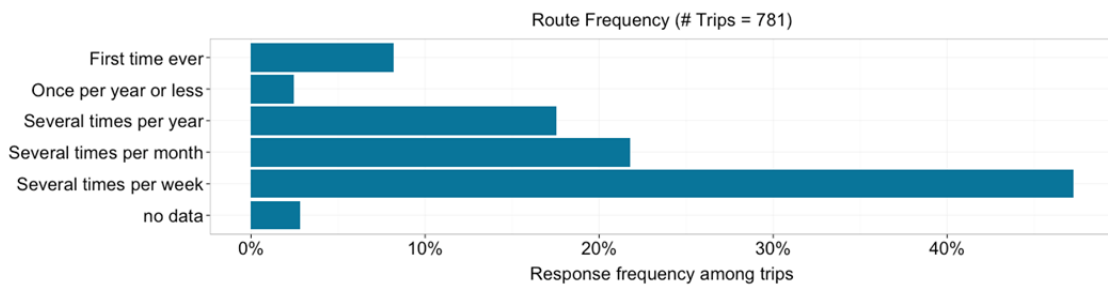


Figure 6.21: Route Frequency Distribution among Trips

6.3.3 Route Comfort

This route comfort question was not mandatory when the application was first released. The route comfort distribution among the trip sample is illustrated in Figure 6.22. Before February 2015 this question was optional and as a result 29% of trips have no data (user declined to provide this information). Of the remaining trips, 24% of trips were indicated to have an "average" comfort level while 28% of trips were indicated to have a "Good (for most riders)" comfort level.

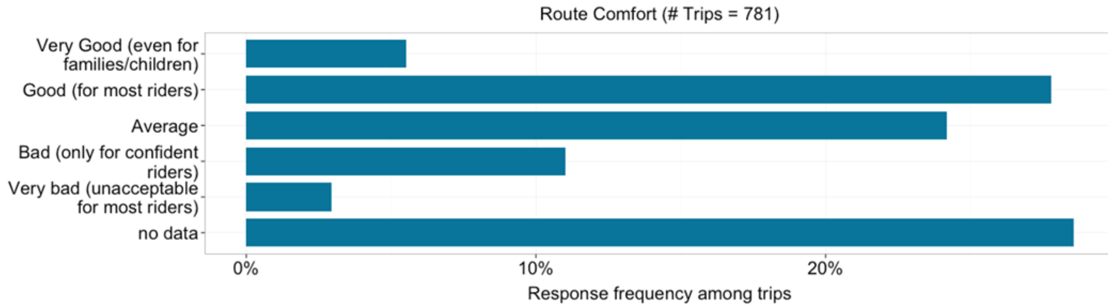


Figure 6.22: Route Comfort Distribution among Trips

6.3.4 Route Preferences

Users were asked to indicate why they chose their particular route for each trip they recorded. This route preference question was mandatory from the outset and could have been answered with multiple responses from among the twelve available options. The route choice preferences distribution among the trip sample is illustrated in Figure 6.23. Nearly 59% of trips were indicated to have been taken on routes that were chosen because they were “direct/fast”. Other popular choices were “It has good bicycle facilities” (37% of trips) and “It has low traffic/low speeds” (30% of trips).

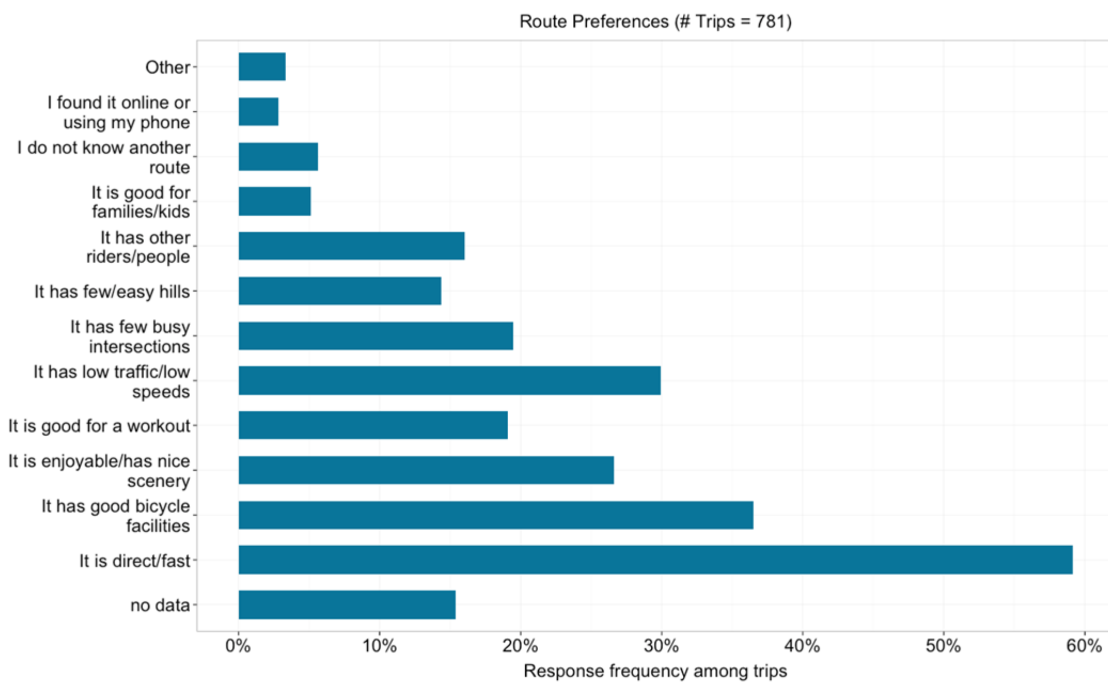


Figure 6.23: Route Preferences Distribution among Trips

6.3.5 Route Stressors

Users were asked to indicate what objects or other transportation modes were a source of concern along the route they had ridden. This question was optional. The route stressors distribution among the trip sample is illustrated in Figure 6.24. Approximately 16% of trips did not have an answer (users declined to provide this information) but on most trips (57%) users indicated that they were concerned about conflicts with auto traffic. Other high categories of concern included large commercial vehicles (27%) and parked vehicles (32%). Cyclists were not concerned for roughly 8% of the trips.

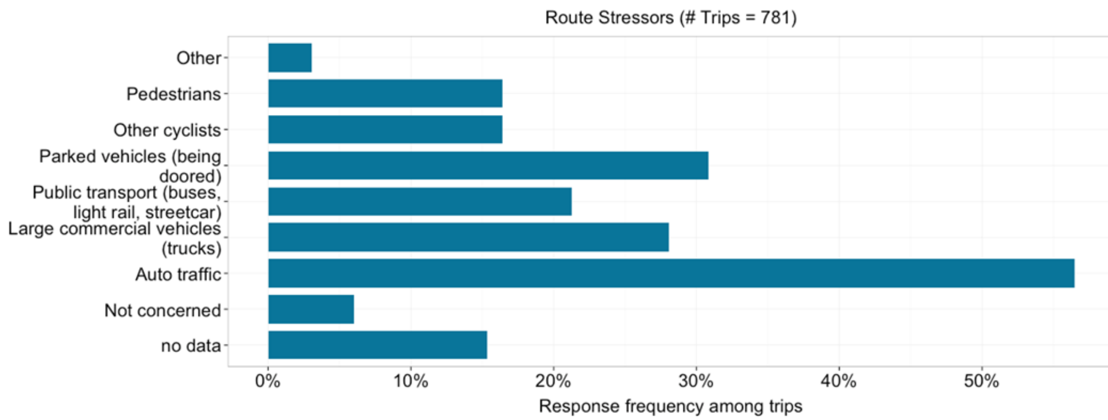


Figure 6.24: Route Stressors Distribution among Trips

6.3.6 Geography

Geographical analysis was used to determine where the trip was taken. The geographic distribution of trips among states is illustrated in Figure 6.25. Over 98% of the trips took place within the state of Oregon and within Oregon (Figure 6.26) 80% of the trips were taken within Multnomah County.

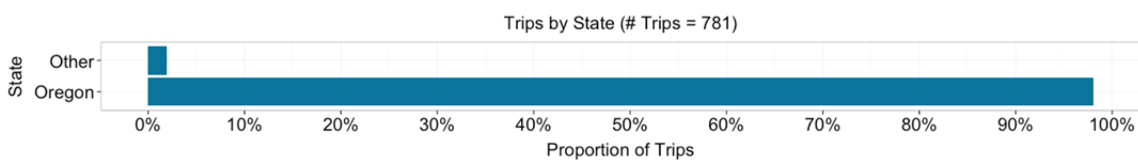


Figure 6.25: State Distribution among Trips

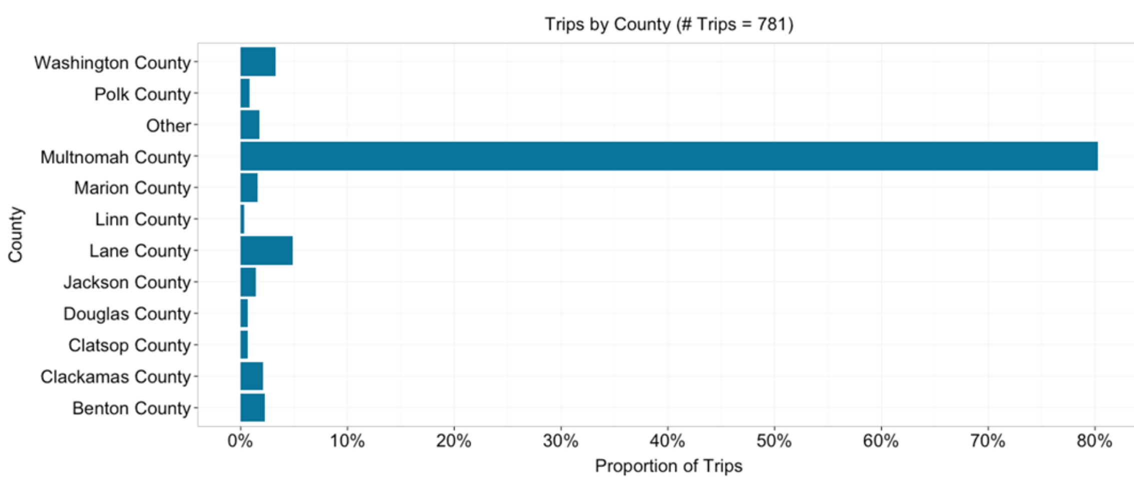


Figure 6.26: County Distribution among Trips

6.3.7 Trip Statistics

Basic statistics for trip times and distances were calculated and separated by trip purpose. Several boxplots are presented below, where the solid black line in the middle of the box indicates the median value, the box itself indicates the inter-quartile range, and the dotted lines indicate the overall range excluding outliers; which are indicated as open circles. As shown in Figure 6.27 trip duration distributions vary substantially among different trip purposes. The overall median trip time was 29 minutes. Exercise trips had the highest median trip duration with 57 minutes whereas transit access trips had the lowest median trip duration with 11 minutes.

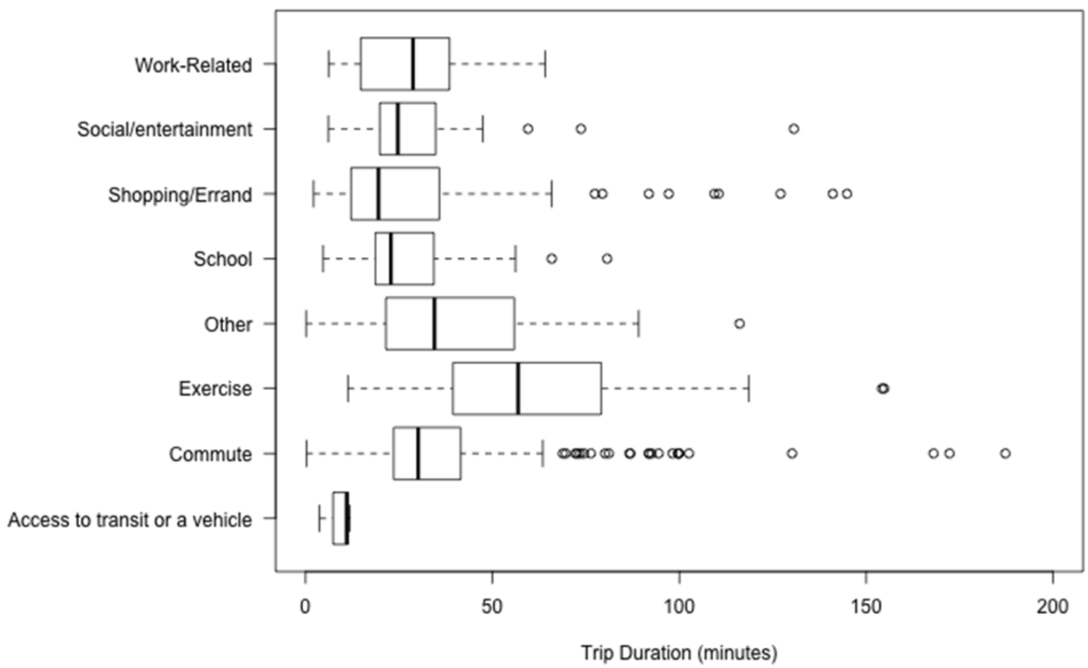


Figure 6.27: Boxplots of Trip Duration distribution by Trip Purpose

Trip distance distributions also vary by trip purpose as shown in Figure 6.28. The overall median trip distance was 4.7 miles. Exercise trips had the highest median trip distance with 11.1 miles, while transit access trips had the lowest median trip distance with 1.8 miles. The trip start time distributions, shown in Figure 6.29, are intuitive. Commuter trips are mostly started around morning and evening peak-hour travel times. Social and entertainment trips tend to start later in the day.

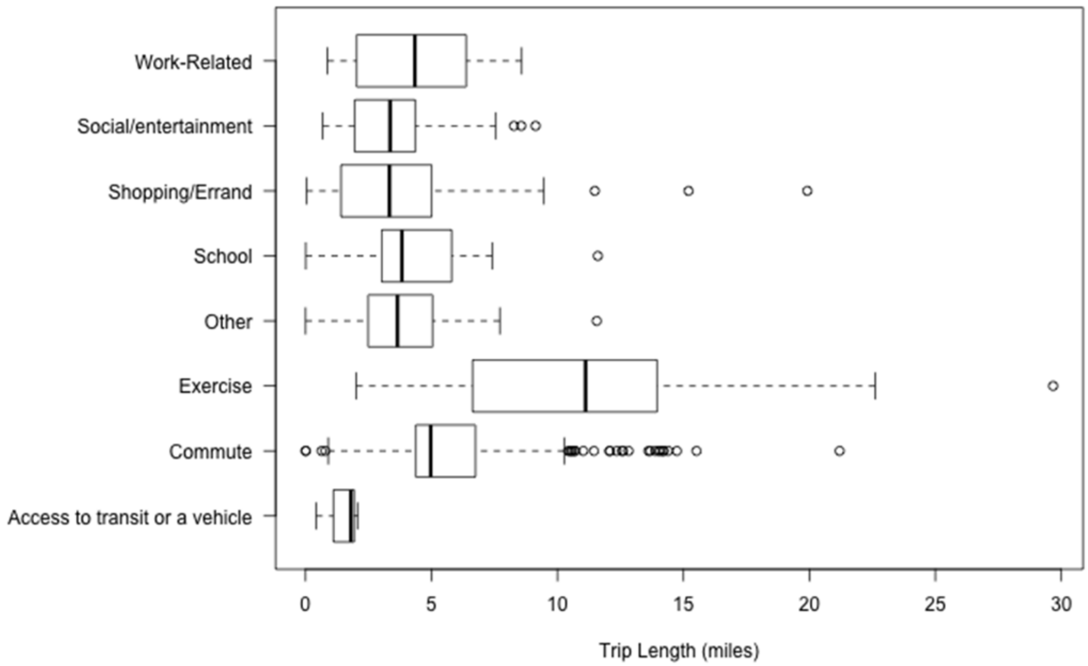


Figure 6.28: Boxplots of Trip Distance distribution by Trip Purpose

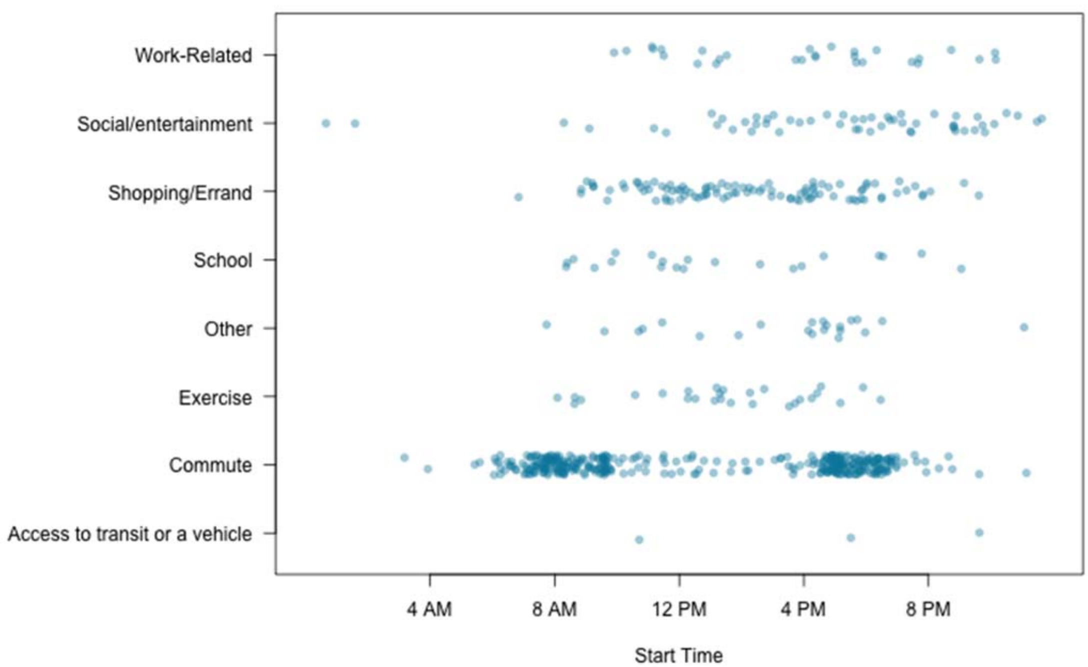


Figure 6.29: Trip Start Time Distribution by Trip Purpose

Finish time distributions for the different trip purposed are presented in Figure 6.30 with a higher concentration of points indicating more trips finishing around that time. The commute trip distribution was multi-modal, as expected, with many trips finishing around 8 AM or 5 PM. The other trip purpose finish times were more evenly distributed throughout the day.

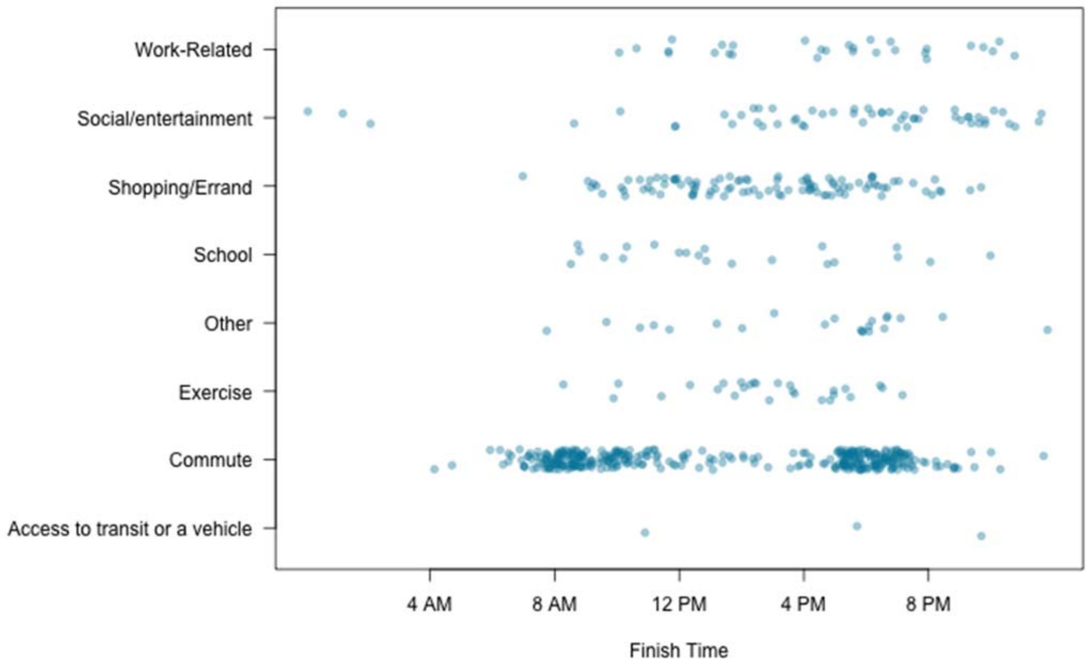


Figure 6.30: Trip Finish Time Distribution by Trip Purpose

6.4 CRASH EVENT AND SAFETY ISSUE REPORT DATA

Reports were also divided into two categories: safety/infrastructure issues and crash events. The rate of report recording and the cumulative number of reports recorded over the study period are graphed in Figure 6.31 and Figure 6.32. Like users and trips, the rate of report recording initially surged with the release of the app but leveled off shortly after. The average report recording rate was 1.7 reports per day. There were 215 reports considered in this analysis with 153 of them being safety/infrastructure issue reports and 62 of them being crash event reports.

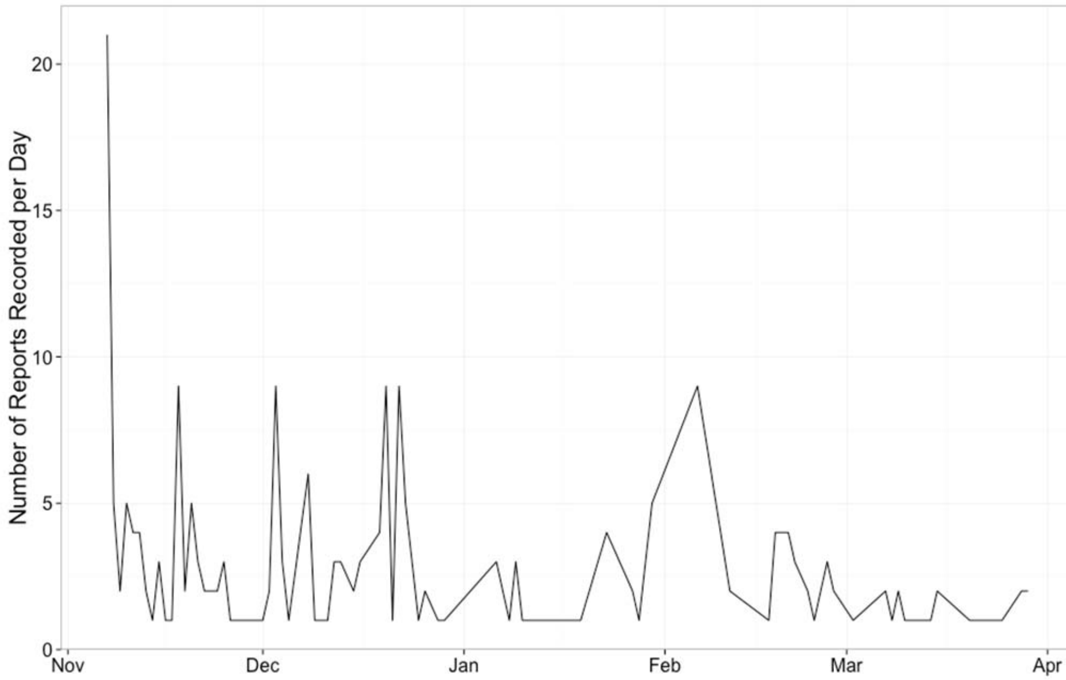


Figure 6.31: Report recording rate over study period

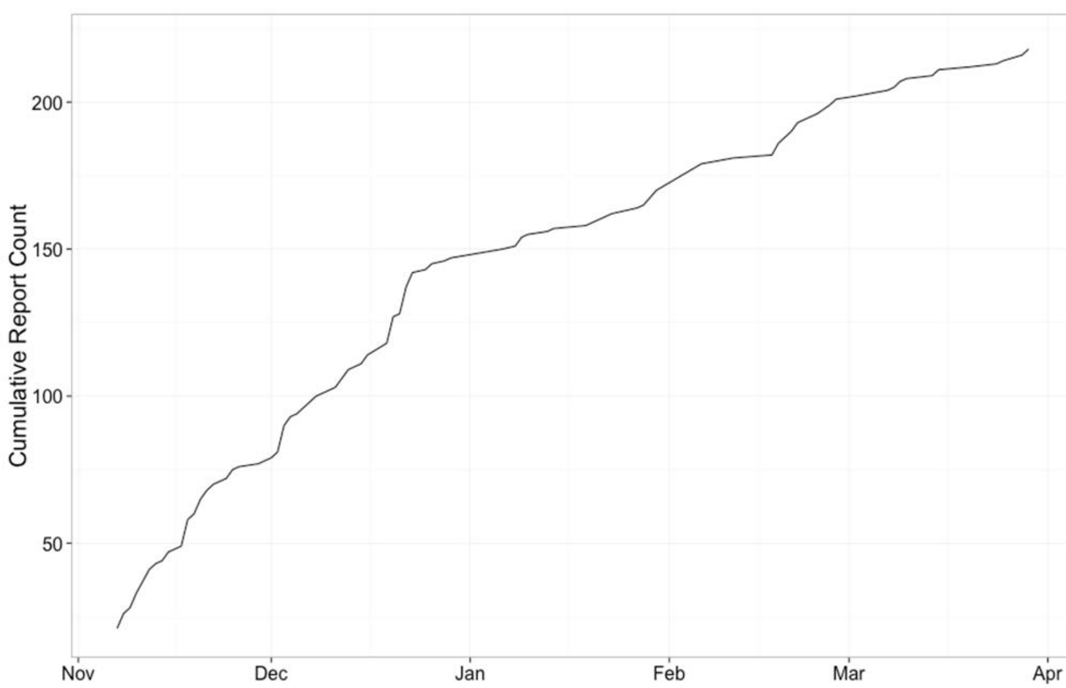


Figure 6.32: Cumulative report count over study period

6.4.1 Crash Event Reports

All questions asked for the crash event reports were mandatory upon reporting a crash event. When documenting a crash event report, users were asked to indicate the severity of the crash event on a 1-5 scale. The majority of crash event reports (62%) were indicated to be near misses; the distribution of severity among crash event reports is illustrated in Figure 6.33.

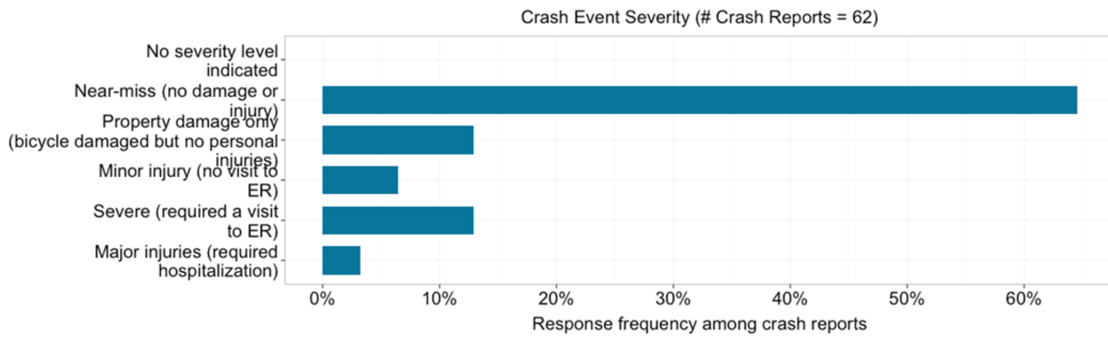


Figure 6.33: Severity Distribution among Crash Reports

Users were also asked to indicate what vehicle or object conflicted with them during the crash event. The conflicting vehicle/object distribution among crash event reports is illustrated in Figure 6.34.

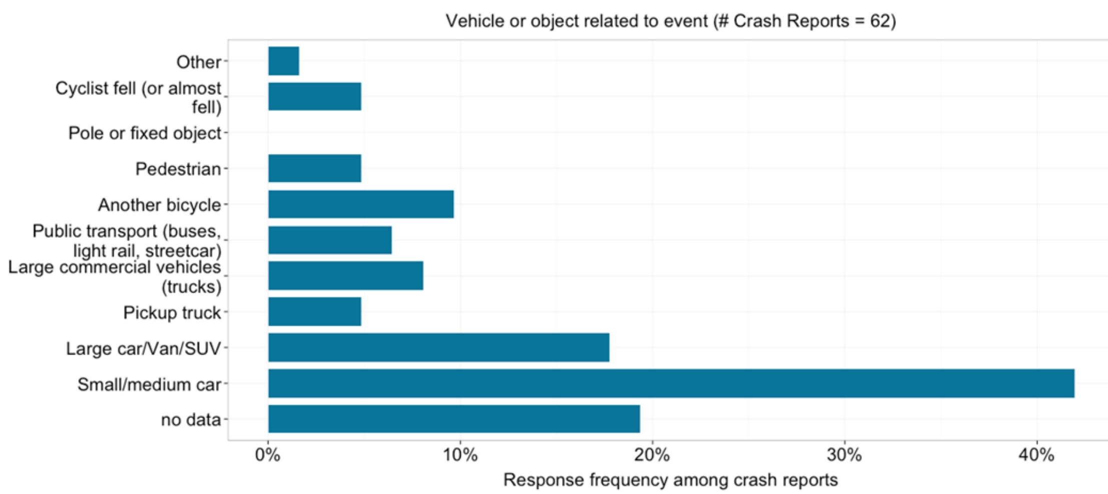


Figure 6.34: Conflict Type Distribution among Crash Reports

Users were asked to indicate actions they felt contributed to the crash event. Users could select from among ten options (including an "other" option with custom text input) and the crash action distribution among crash events is illustrated in Figure 6.35. Figure 6.36 shows the explanations or reasons related to the crash event.

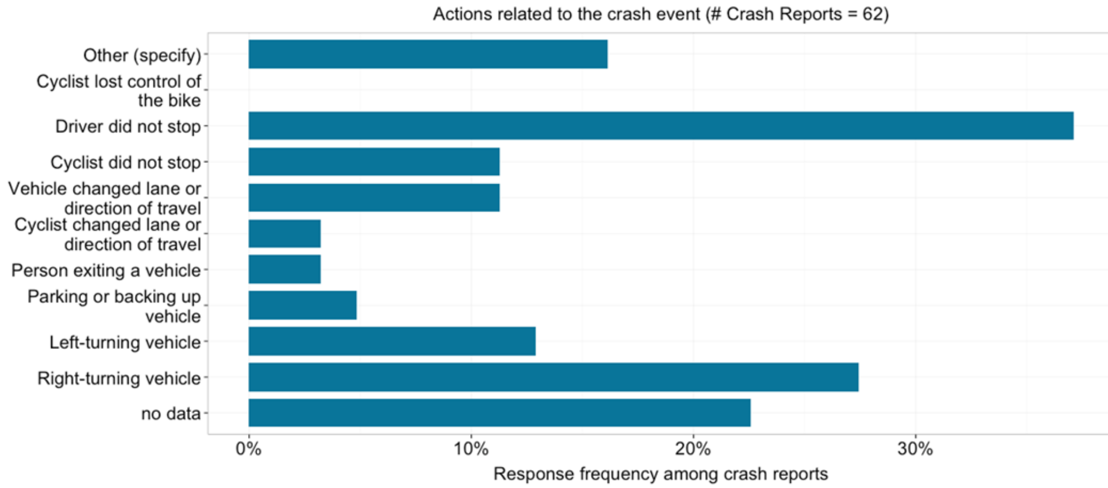


Figure 6.35: Crash Actions among Crash Reports

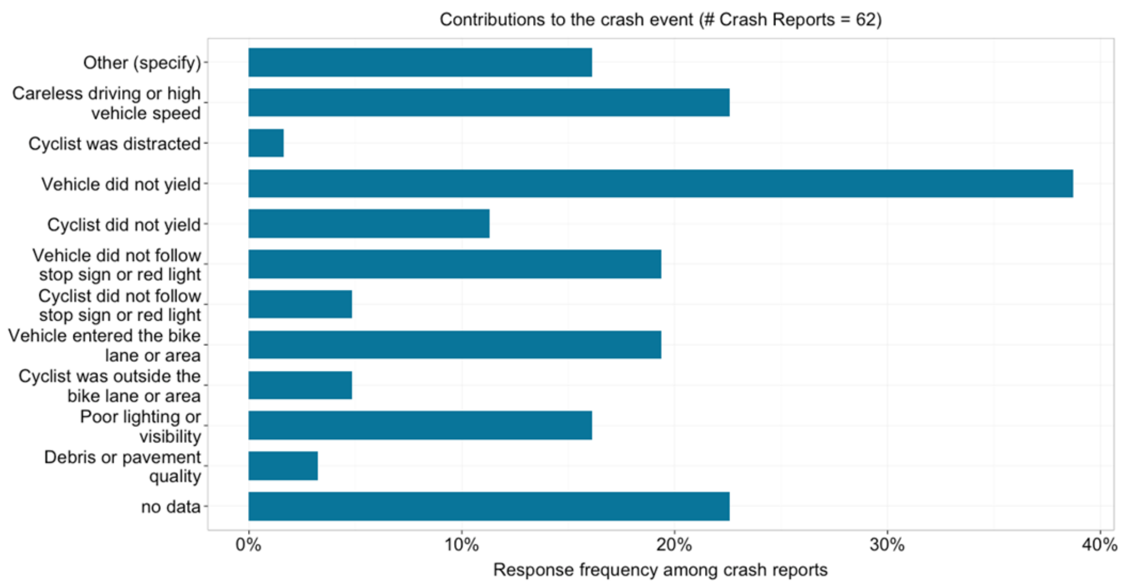


Figure 6.36: Crash Reasons among Crash Reports

Geographic analysis was used to separate crash event reports by state and the 95% of the crash event reports were located within Oregon and 92% of the reports in Oregon were located in Multnomah County. The geographic distribution of crash reports among states is illustrated in Figure 3.7 and among counties in Figure 3.8.

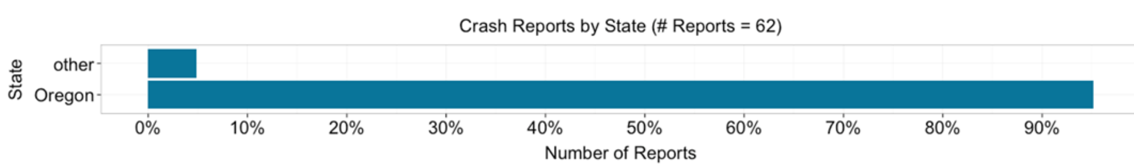


Figure 6.37: State Distribution among Crash Reports

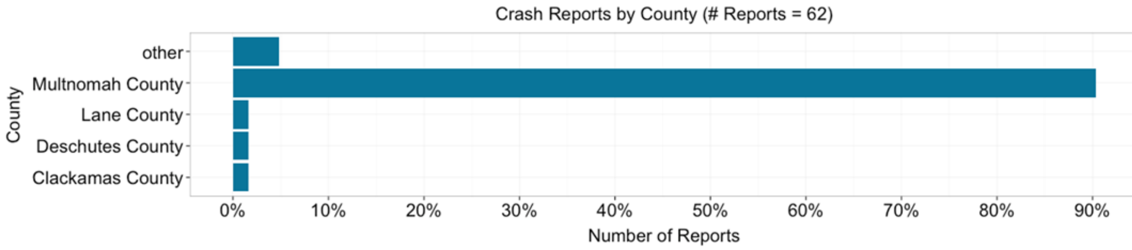


Figure 6.38: County Distribution among Crash Reports

6.4.2 Safety/Infrastructure Reports

Users were asked to identify what type of issue they were reporting. Users could select one or more of fourteen options and provide custom text input for the "other" option; the distribution is shown in Figure 6.39. Nearly 33% of the reports had "High traffic volume" and nearly 32% of the reports had "other" indicated.

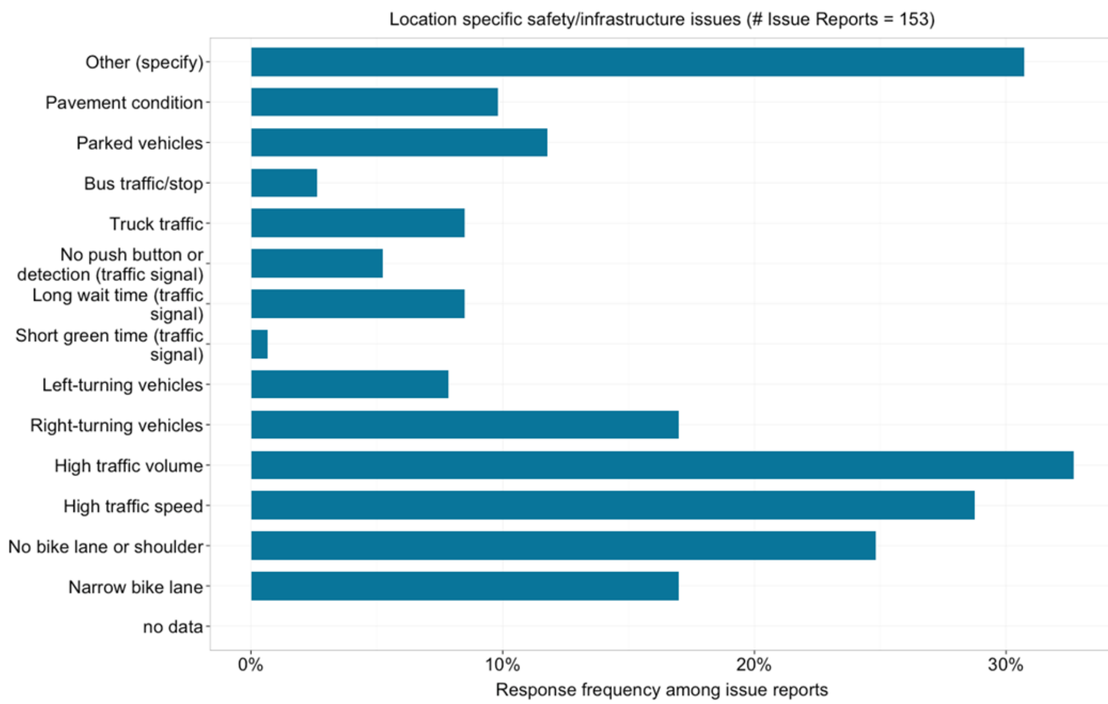


Figure 6.39: Issue Type Distribution among Safety Issue Reports

When reporting a safety issue users must select one option on a 1-5 scale of urgency, with 1 being the least urgent and 5 being the most urgent. The urgency distribution among safety issue reports is illustrated in Figure 6.40 and the majority of issues were concentrated in the 3 and 4 categories (53%).

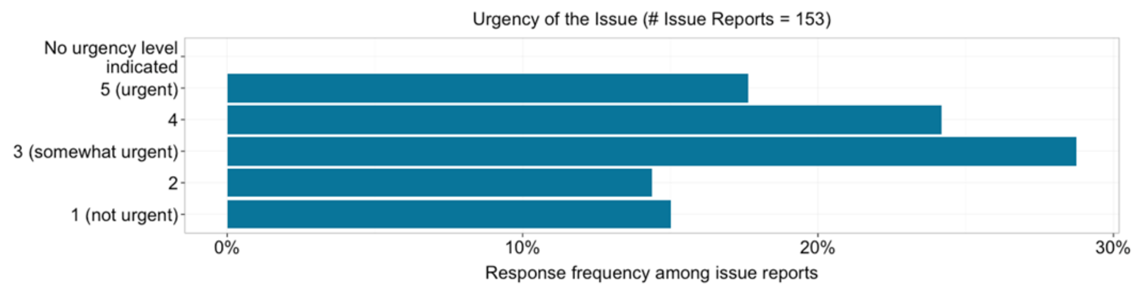


Figure 6.40: Urgency Distribution among Safety Issue Reports

Geographic analysis was used to separate issue reports by state. The geographic distribution of safety issue reports among states is illustrated in Figure 6.41; nearly 10% of the issue reports came from other states. The geographic distribution of safety issue reports among counties is illustrated in Figure 6.42. The majority (67%) of reports were made in Multnomah County. Nearly 10% of the reports were made in "other" counties, which included reports outside of Oregon. The geographic distribution of safety issue reports among counties is illustrated in Figure 6.42.

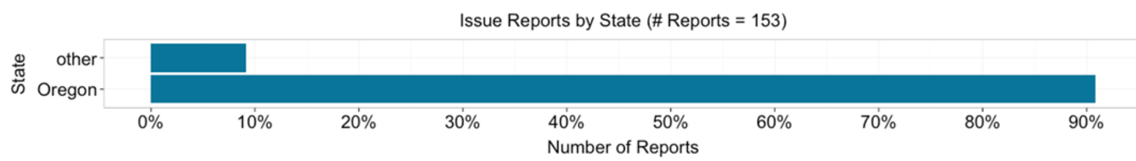


Figure 6.41: State Distribution among Safety Issue Reports

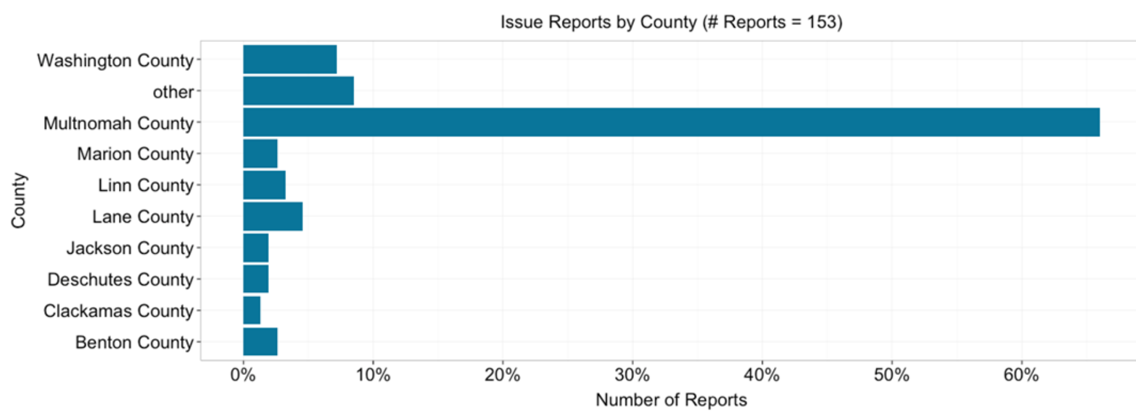


Figure 6.42: County Distribution among Safety Issue Reports

6.5 EXPLORATORY ANALYSIS OF COMFORT DATA

A goal of the research was to analyze the suitability of ORcycle data to analyze LTS and route comfort level. This subsection explores how comfort level can be estimated as a function of trip or user characteristics.

The response to the "route comfort" question can be used as a dependent variable utilizing a cumulative logistic regression approach. This approach has been used in several levels of service models *(Jensen 2007; Ali et al. 2012; Foster et al. 2015)*. Logistic regression models are used to model categorical dependent variables. Cumulative logistic regression models (also known as ordinal logistic regression models) are used to model categorical dependent variables of an ordered nature. The cumulative logistic regression model results presented herein were constructed using the R package "ordinal"[52], which offers many tools for statistically modeling ordinal outcome variables.

In all of the models tested, the route comfort rating was the dependent variable. For continuous variables, a single variable cumulative logit model was tested for each variable to assess the relationship of that variable to route comfort (in terms of significance, magnitude, and direction) alone. For categorical variables, the Chi-Square test of independence was used to test for a statistically significant relationship between the variable of interest and route comfort. In this test, the null hypothesis is that the variable of interest has no relationship with route comfort; which would be rejected in the case of the Chi-Square statistic being statistically significant. The following independent variable groups were explored separately (one variable at the time): (1) trip attributes (length, duration, and average speed), (2) trip temporal characteristics, (3) user-reported trip characteristics (e.g. trip purpose and route stressors), and (4) user attitudes and socio-demographics.

This is just an exploratory study and the reader should be reminded that the results presented herein may not hold in a model with multiple variables and interactions. Each of these variables can be correlated with other variables in the ORcycle dataset and more advanced specifications such as non-linear models or segmentation should be also explored. The reader is also reminded that correlation or statistical significant does not necessarily mean causality. Finally, this is the first study of route comfort utilizing revealed GPS route data and that winter cyclists are largely represented in the sample data. Hence, results must be interpreted with due caution.

6.5.1 Trip Attributes

Three trip attributes were calculated: trip length (miles), trip duration (minutes), and average trip speed (miles per hour). A script was run to remove trip ends where the user forgets to stop the application. These trip attribute variables were tested for significant relationships with route comfort and trip length and average speed had significant and negative signs as shown in Table 60. Results suggest that longer trips tend to have lower comfort levels and that routes with a higher average speed tend to be less comfortable. Later results show that routes that are chosen because they are direct and fast tend to have a negative coefficient as well. It is not possible to determine a causality direction and these results should be taken with caution as this is just an exploratory study.

Table 6.9 Results suggest that longer trips tend to have lower comfort levels and that routes with a higher average speed tend to be less comfortable. Later results show that routes that are chosen because they are direct and fast tend to have a negative coefficient as well. It is not possible to determine a causality direction and these results should be taken with caution as this is just an exploratory study.

[52] http://www.cran.r-project.org/package=ordinal/

Table 6.9: Trip attribute variable definitions

Variable Description	Data Range	z-statistic in single variable cumulative logit	Statistical Significance
Trip length	Min: 0.30 miles Max: 29.67 miles	-2.389	$p<0.05$
Trip duration	Min: 2.51 minutes Max: 166 minutes	0.087	Not significant
Average speed	Min: 0.63 mph Max: 16.83 mph	-2.282	$p<0.05$

6.5.2 Temporal Characteristics

The impacts of time of day and day of the week on comfort levels were also tested. The time a trip started was used to categorize these temporal variables into two groups representing weekday/weekend travel as well as peak and off-peak time travels. The corresponding variable definitions are outlined in Table 6.10; only weekday was significant and had a negative relationship. Given the large number of commuter trips in the sample, the weekday variable may indicate that traveling during days/times with high traffic volumes tend to decrease route comfort.

Table 6.10: Temporal characteristics variable definitions

Variable Description	Possible Values	Chi-Square, DF	Statistical Significance
Trip day-of-week category	• Weekday • Weekend	10.57, 8	$p<0.05$
Trip start time category	• Off-Peak Night (6:30 PM to 7:00 AM) • Peak AM (7:00 AM-9:00 AM) • Off-Peak Day (9:00 AM to 4:30 PM) • Peak PM (4:30 PM to 6:30 PM)	8.65, 18	Not significant

6.5.3 Trip Route Choice

Many route choice factors were significant; results are contained in Table 6.11. As mentioned previously, routes chosen because they are fast and direct tend to be less comfortable. When users do not know or have another alternative route comfort levels are also lower. On the other hand, comfort increased when routes were chosen because they: had good bike facilities, were good for families, had enjoyable or nice scenery, had low traffic volumes or speeds, or had few busy intersections.

Table 6.11: Route Choice Factors

Variable Description	Possible Values of Variable (range for Continuous variables)	z-statistic in variable group cumulative logit model	Statistical Significance
User chose this route because it was direct or fast.	True/False	-8.49	p<0.001
User chose this route because it has good bicycle facilities.	True/False	4.08	p<0.001
User chose this route because it is enjoyable or has nice scenery.	True/False	1.97	p<0.05
User chose this route because it is good for a workout.	True/False	-0.54	Not significant
User chose this route because it has low traffic or low vehicle speeds.	True/False	3.51	p<0.001
User chose this route because it has few busy intersections.	True/False	2.76	p<0.01
User chose this route because it has few and/or easy hills.	True/False	0.64	Not significant
User chose this route because it has other riders/people.	True/False	1.64	Not significant
User chose this route because it is good for families/kids.	True/False	3.71	p<0.001
User chose this route because they do not know another route.	True/False	-3.24	p<0.01
User chose this route because they found it online or using their phone.	True/False	1.28	Not significant
User chose this route for some other reason.	True/False	-0.82	Not significant

Intuitive results were also obtained regarding route stressors. Routes without any stressors were significantly more comfortable than routes were users chose a stressor such as traffic, commercial vehicles, or other cyclists; variable definitions and results are shown in Table 6.12. With the exception of cycling frequency, all user demographic and attitude questions were also significant after performing a Chi-square test.

Table 6.12: User question response variable definitions

Variable Description	Possible Values of Variable (range for Continuous variables)	z-statistic in variable group cumulative logit model	Statistical Significance
User indicated that on this route they were not concerned with traffic stressors.	True/False	4.23	$p<0.001$
User indicated that on this route they experienced discomfort as a result of auto traffic.	True/False	-2.81	$p<0.01$
User indicated that on this route they experienced discomfort as a result of large commercial vehicles/trucks.	True/False	-8.11	$p<0.001$
User indicated that on this route they experienced discomfort as a result of public transport.	True/False	-1.57	Not significant
User indicated that on this route they experienced discomfort as a result of parked vehicles.	True/False	0.92	Not significant
User indicated that on this route they experienced discomfort as a result of other cyclists.	True/False	2.17	$p<0.05$
User indicated that on this route they experienced discomfort as a result of pedestrians.	True/False	1.62	Not significant

6.6 LIMITATIONS OF THE EXPLORATORY COMFORT ANALYSIS

Limitations associated to modeling one variable at the time were already mentioned earlier. In addition, there are some additional limitations associated to user sample biases, user participation, the presence of mixed facilities per trip, multiple imputation of data, and the small number of observations for certain variables.

The user, trip, and report samples were all collected between the beginning of November 2014 and the end of March 2015. Though this time period was a relatively mild winter[53] in Oregon, winter cyclists are typically different than their fair-weather counterparts *(Damant-Sirois et al. 2014; Ahmed et al. 2012)*. Within the user sample, there are potentially biases resulting from the method of data collection; namely that it was necessary to have access to an iOS or Android smartphone to participate in the data collection. Among potential users that did own smartphones, there were also likely differences among those who would be willing to participate in the ORcycle data collection. There were also likely differences among those who uploaded many trips and/or reports when compared to users who only uploaded minimal data. User sample biases are quantified in section 6.2 through comparisons with a travel survey dataset from the Oregon Household Activity Survey. The results presented in section 6.2 are somewhat favorable but most of these biases can be potentially mitigated by expanding the data sample and the proper utilization of weights to correct for over or underrepresentation of certain groups.

In a trip there may be multiple facilities and levels of comfort along the route but the user is only providing one number (or average) for the whole trip. Ideally, users would report comfort levels and route stressors by segment(s) or even at the intersection level. However, this change is likely to require a major research and coding effort.

Where survey responses were missing, a multiple imputation algorithm was used to generate likely survey responses. Missing survey responses were generated based on the other responses that had been made for a trip and the responses that had been made for similar trips. This problem will not be so important in the future because the latest ORcycle version release in March has many more mandatory questions (especially for key variables). Finally, several of the categories, had small frequencies and this may have affected the statistical significance results presented earlier.

[53] http://www.ktvz.com/news/as-oregons-warm-winter-ends-snowpack-worries-rise/31718584

7.0 CONCLUSIONS

The ORcycle smartphone application was developed successfully. ORcycle combines GPS revealed route data collection with new questionnaires that try to elicit cyclists' attitudes as well as comfort levels and factors that influence their perceived comfort and route choice. The new questionnaires were developed to better understand how cyclists' comfort levels are affected by route characteristics, route stressors, safety reports, cyclists' demographics, and cyclists' cycling attitude. Preliminary results show that many trip characteristics, route choice factors, route stressors and demographic variables are correlated with comfort levels.

Although this is a preliminary analysis many of the results are novel because the ORcycle dataset is unique. For example, to the best of the authors' knowledge, no other study has quantified the impact of route choice factors on comfort levels. The rest of this section explores potential applications of ORcycle data, presents a summary of lessons learned and ends with final thoughts.

7.1 POTENTIAL ORcycle APPLICATIONS

7.1.1 LTS Applications

The LTS modeling results presented in this report are part of an exploratory study where variables are analyzed one at the time utilizing cumulative logistics models (a.k.a. ordinal logistics models). A complete modeling effort will require many more steps including the analysis of correlations among independent variables as well as the analysis of informative interactions among variables. For example, to quantify the impact of peak hour traffic on comfort levels, especially on direct routes for commuters, is the interaction between short/fast route selection and time of day variables.

The preliminary study *only* explored a subset of variables and one variable at the time; i.e. if there was a relationship between route comfort and some trip attributes (length, duration, and average speed), trip temporal characteristics (weekday/time of day), route choice factors, route stressors, user attitudes, and socio-demographics.

Many potentially important and useful variables should be explored in the future. Some of these variables include: bicycle facility and street typology, topography, traffic volume, and roadway posted traffic speed. With a large number of observations it may be even possible to explore what design elements affect comfort, e.g. bulb outs, chicanes, and speed bumps in a bicycle boulevard. Some of these variables such as facility type, traffic volume, and traffic speed are the key variables currently used to determine LTS levels. However, before performing this study is necessary to geo-match GPS coordinates to a GIS network already loaded with the roadway type, bicycle facilities, traffic volume, and traffic speed attributes. This task is beyond the scope and budget of this research project.

A comprehensive comfort modeling study must simultaneously study pooled (i.e. not one variable at the time) models were many groups of variables are jointly estimated. It is possible to estimate cumulative logistic regression models by carefully running forward or backwards stepwise regressions.

Based on the results observed in the pilot study it seems possible to calibrate cyclist LTS levels utilizing empirical data from Oregon facilities and users. The current LTS levels seem intuitive but have not been yet empirically validated. In addition, potential applications include the development of LTS tables that target different demographics (age, gender, etc.), trip purposes (e.g. commuters vs. recreational), as well as urban vs. suburban or rural environments.

7.1.2 Prioritization of Network Improvements

Cyclists' routes by comfort levels and purpose can be compared to shortest paths to identify long detours. By identifying mismatches between actual routes and shortest paths transportation planners can identify where users take longer detours that lead to more comfortable routes; it is also possible to identify nodes or areas along the shortest paths where improvements are needed.

Previous LTS work has also utilized the existing tables to identify islands or areas that are not connected by links with adequate LTS level. The same can be done by utilizing revealed data. A unique feature of ORcycle is that users can also submit reports regarding safety issues and crashes; this is an additional source of data that can complement route comfort and LTS data. Similarly, it may be possible to perform before/after analysis of bicycle infrastructure improvements and how new infrastructure impact route comfort levels. Given uninterrupted ORcycle data planners can quantify the difference in volumes using a particular facility after it is improved. Perhaps more importantly, planners can use the demographic questions associated with cyclists to see if different *types* of cyclists are using a new facility. Further, transportation planners can analyze if the comfort experienced by a single cyclist (or group) changed with the provision of new infrastructure.

7.1.3 Crash and Injury Risk Models

Researchers in Montreal have successfully combined GPS routes from Mon RésoVélo with bicycle counts and geocoded crash data to develop an injury risk model *(Strauss et al. 2015)*. The GPS traces from the Mon RésoVélo application were combined with point bicycle counts to form bicyclist exposure rates for each link in Montreal's network. The crash/injury data is then modeled over the exposure rates to model the risk of injury in the network. The data from ORcycle in combination with bicycle counts and geocoded crash data could be used to reproduce or improve upon this modeling in Oregon. ORcycle dataset has the potential to build an enhanced crash model since it also collects crash information from its users.

7.1.4 Oregon User Types

When compared with previous applications, ORcycle has more demographic and cyclist type questions, more details about riders' trips, and more safety data. Factor and cluster analyses could be used to group Oregon cyclist types. While Geller's "Four types of cyclists" methodology *(Geller 2006)* is widely cited as a satisfactory cyclist typology for cyclist planning (in Portland and elsewhere), the categories are based on limited empirical data. Geller's original categorization in 2006 made educated guesses about the proportion of the Portland population falling with the four categories. Geller's proportions were approximately validated by a randomized phone survey *(Dill and McNeil 2012)*. However, this typology was not validated using revealed preference data and has not been validated outside of Portland.

This application could be crucial to validate assumptions about what facility types are preferred by different types of cyclists in different types of environments that include not also urban but also suburban and rural areas.

7.1.5 Enhanced Route Choice Models

Oregon Metro's bicycle route choice model was developed utilizing empirical data collected in Dill and Gliebe's bicycle GPS study *(Dill and Gliebe 2008)*. While this model was a positive development it was based on a relatively small sample of cyclists (164 cyclists) and trips (1,449 trips); in addition, most trips are contained within the limits of the City of Portland. As ODOT and other local transportation agencies make cycling an increasingly central focus of their transportation planning efforts, it will be useful to develop bicycle route choice models to effectively analyze and predict the needs of growing cycling populations in other urban networks with high connectivity. In suburban and rural areas LTS data and analysis can be utilized to identify links that need to be improved.

7.2 LESSONS LEARNED

This type of project is very demanding in terms of research skills and staffing. In the future, the ORcycle smartphone app will require maintenance and/or updates. Necessary skills to successfully develop and implement ORcycle includes: iOS programming, android programing, php and sever programming, database management, statistical analysis, and survey design. It is impossible to find a research assistant with all these skills. In general it necessary to have, as a minimum, a programmer for iOS, a programmer for android, a database and server developer, and a transportation analyst. An additional research assistant may be necessary to develop advance mapping and website features. Staffing was a demanding task and given the current "hot" market for programmers it is hard to attract and retain highly qualified programmers. For all the staff involved in the project there was a steep learning curve to learn the idiosyncrasies of programming specific to GPS, mapping, and questionnaires in a transportation context.

Work that involves programming and application development in many cases generates unforeseen delays or the later discovery of bugs and hidden problems after the application is released. A rigorous testing and piloting procedure was followed during the development of the ORcycle application and so far no problems or issues have been detected or reported. Most of the user feedback has been highly positive and cyclists seem to appreciate the opportunity to provide feedback and contribute to the improvement of modeling tools and cycling infrastructures. Some cyclists suggested the idea of combining ORcycle with other bicycle applications to track routes and distances; other cyclists supported the concept of providing data to improve cycling and objected to the idea of commercial applications selling user data to transportation agencies. Providing on-line maps of all routes taken with some way to see individual routes and their states (miles, time, calories expended, GHG benefits, elevation changes, etc.), might entice people to use ORcycle.

Participation and support from transportation agencies staff are key ingredients to promote the ORcycle application and engage users. The promotion of ORcycle was mostly based on email campaigns plus some short interviews in radio programs and a brief blurb in BikePortland and other press outlets. Moving forward it is not evident what the best ways are to engage a diverse and large population of cyclists. Promoting the application during the summer months seems an obvious start but further research is necessary to understand the effectiveness of different promotional outlets (free and paid). Other options that might be considered includes outreach to bike retailers to provide coupons for sales where user matches our underrepresented groups. Other outreach venues may include schools, day laborer sites, and retirement homes.

A very strict privacy was followed in the development of ORcycle. This was in part due to the requirement of the Portland State University Internal Review Board (PSU IRB) and in part by design. ORcycle ask users for personal data as well as email and GPS traces that can potentially identify the users' household or employment location. Strict privacy protocols have been implemented to safeguard users' data. Raw data is always stored in password protected servers and researchers working in this project have been trained in best practices and protocols to safeguard users' data. Users' feedback indicates that this approach has been well received and appreciated by users that do not want their data to be distributed without their consent, sold, or utilized for non-ORcycle related goals.

7.3 FINAL THOUGHTS

A project of this size and complexity required a great deal of teamwork and the development of new technical skills among all members of the research team. Developing and distributing a smartphone application capable of crowdsourcing the type of data analyzed herein is likely a task most transportation agencies are not currently equipped to handle without support from universities or outside consultants.

The original goal of this project was to develop an application to crowdsource bicycle data and carry out a pilot study to evaluate if smartphone data can be useful to fill some of the existing cycling data gaps at the state level. The level of participation observed and the quality of the data gathered indicates that a smartphone application to gather cyclists' data is worth pursuing. The depth of the gathered cyclist data is unprecedented and cannot be matched by other traditional and more expensive ways of collecting cyclists' data (e.g. counts, household surveys, etc.). However, the potential of the ORcycle dataset is compounded if it can be complemented with other sources of data such as counts and crash databases or accurate GIS files with accurate roadway data. For example, to further investigate the impact of bicycle facilities it is necessary to utilize GIS data and geo-matching algorithms to convert GPS coordinates into paths (nodes and links) of a network. ORcycle can potentially generate panel data and utilized to study trends over time; this type of panel study has never been done.

The results of this research project present three main sources of value for transportation researchers and planners: (1) a smartphone application for iOS and Android platforms that was successfully deployed and utilized to gather high-quality cyclists' data, 2) a successful and novel exploratory study of some of the variables that affect route comfort, and 3) a list of potential applications and future research steps that can take advantage of the ORcycle application.

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