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Feasibility of Using GPS to Track Bicycle Lane Positioning

Final Report

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16. Abstract (Limit: 250 words)

Researchers have shown that GPS units in smartphones can be used to identify routes taken by cyclists, including whether cyclists deviate from shortest paths to use bike lanes and other facilities. Researchers previously have not reported whether GPS tracking can be used to monitor whether and how bicyclists actually use lanes on streets, where these lanes have been provided, or other types of facilities. The objective of this research was to determine whether smartphone GPS units or enhanced GPS units could be used to track and map the location of cyclists on streets. The research team modified an open-source smartphone application (CycleTracks) to integrate with a higher-quality external GPS unit. Cyclists then mounted the smartphone with route-tracking applications to bicycles and repeatedly rode four different routes. The routes for the field tests were chosen because each included a striped lane for bicycle traffic and because the routes bisected a variety of built urban environments, ranging from an open location on a bridge over the Mississippi River to a narrow urban street lined by tall, multi-story office buildings. The field tests demonstrated that neither the smartphone GPS units nor the higher-quality external GPS receiver generate data accurate enough to monitor bicyclists' use of bike lanes or other facilities. This lack of accuracy means that researchers interested in obtaining data about the propensity of cyclists to ride in lanes, when available, must rely on other technologies to obtain data for analyses.

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Executive Summary

Researchers have shown that GPS units in smartphones can be used to identify routes taken by cyclists, including whether cyclists deviate from shortest paths to use bike lanes and other facilities. Researchers previously have not reported whether GPS tracking can be used to monitor whether and how bicyclists actually use lanes on streets, where these lanes have been provided, or other types of facilities. The objective of this research was to determine whether smartphone GPS units or enhanced GPS units could be used to track and map the location of cyclists on streets. The research included three tests:

1. A comparison of the accuracy of the smartphone application GPS tracking system vs. a high-quality external GPS unit.
2. A comparison of the accuracy of GPS measurements in various urban environments (e.g., urban canyons vs. bridges or other open streets).
3. A comparison of smartphone performance among various manufacturers (e.g., LG vs. Motorola).

To complete these tests, the research team modified an open-source smartphone application (CycleTracks) to integrate with a higher-quality external GPS unit. Cyclists then mounted the smartphone with route-tracking applications to bicycles and repeatedly rode four different routes. The routes for the field tests were chosen because each included a striped lane for bicycle traffic and because the routes went through a variety of built urban environments, ranging from an open location on a bridge over the Mississippi River to a narrow urban street lined by tall, multi-story office buildings.

Statistical analyses of field tests demonstrated that:

1. The GPS route traces provided by the external GPS units were significantly more accurate than the traces provided by the GPS units in the smartphones;
2. The route traces provided by both the standard GPS and the external GPS were affected by the characteristics of the built environment along the route. The accuracy of the route traces in the “urban canyon” was significantly different (lower) than the accuracy along other routes. The accuracy of the traces over the bridge was highest.
3. No significant differences in the accuracy of traces from different smartphones were observed.

The field tests also demonstrated that neither the smartphone GPS units nor the higher-quality external GPS receiver generate data accurate enough to monitor bicyclists’ use of bike lanes or other facilities. This lack of accuracy means that researchers interested in obtaining data about the propensity of cyclists to ride in lanes, when available, must rely on other technologies to obtain data for analyses. Because GPS data are sufficiently accurate to determine routes taken, researchers can infer decisions by cyclists to deviate from shortest-path routes to use bike facilities. Future improvements in GPS technology may facilitate the types of applications envisioned in this research.

Chapter 1. Background and Motivation

Federal, state, and local governments are investing hundreds of millions of dollars in bicycle facilities to achieve an array of objectives, including more sustainable transportation systems. However, information about how cyclists use these facilities and how their patterns of use affect traffic safety generally is lacking. The general aim of this research is to increase understanding of the behavior of cyclists in urban traffic, specifically their use of bicycle facilities like marked bicycle lanes on urban streets.

Researchers now are developing strategies for monitoring bicycle traffic using recent technological innovations, including the global positioning systems (GPS) in smartphones. Some progress has been made in monitoring bicycle volumes using new technologies such as inductive loop detectors or infrared monitors (e.g., BTS, 2000; DPW, 2011; Handy, 2009; Jones, 2009; Lindsey et al., 2007, FHWA 2012) but these technologies provide only counts of bicyclists and little information about how cyclists use specific facilities. Less research has been completed on the behavior of cyclists on bicycle facilities, and most of this information has been collected through video or manual field observations (e.g., Hunter et al. 2011, Marquardt, K., Flunker, D., and Handon, M. 2012**)**.

Researchers recently have reported results of efforts to monitor routes taken by bicyclists using data from GPS units (e.g., Hood et al., 2011; Dill, 2009). Hood et al. (2011) demonstrated that route traces from GPS units in smartphones could be used to inform transportation route choice models. By comparing routes taken by cyclists to shortest routes between origins and destinations determined through geographic information system (GIS) network analysis, they were able to determine factors that influenced cyclists' choices of routes. For example, through comparison of actual routes taken to shortest paths, researchers determined that some riders went out of their way to ride on streets with bike lanes, presumably for safety reasons, or to avoid hills. These data then informed construction of route choice models used by the San Francisco Transportation Planning Authority. This type of practical application now is being replicated by other transportation planning agencies, including, for example, the Met Council in the Twin Cities metropolitan area in Minnesota.

Other researchers also are exploring how cyclists use facilities (e.g., whether they ride in marked bicycle lanes or in adjacent parking lanes) and how they interact with vehicular and pedestrian traffic. Most of these studies have involved field observations or analyses of video tape to ascertain location of cyclists on streets and their interactions with vehicles or pedestrians. Hunter et al. (2011, p. 79), for example, through analyses of videotapes of bicycle traffic, concluded that painting of sharrows – shared lane markings – on streets generally reflected "more segregated flow with less lateral movement of bicycles and motor vehicles." In an analysis of shared lane marking in San Francisco, Alta Planning + Design (2004) reported that the markings were associated with reductions in riding on sidewalks, more space between cyclists and parked vehicles, and more space between cyclists and vehicles during passing events, and more space between moving and parked vehicles when no cyclists were present.

The specific aim of this research was to test the feasibility of using a smartphone bicycle route tracking application – CycleTracks – with both standard and enhanced GPS to determine whether route traces are sufficiently precise to enable tracking the use of facilities such as bicycle lanes or bike boxes. The practical motivation is to identify a method that planners could use to document the proportion of cyclists that use bicycle facilities as designed (i.e., in compliance with street markings). The principal research question is whether, in addition to the street or route taken, GPS tracking also can be used to identify the specific locations where cyclists ride on a street.

Following this introduction, Chapter 2 of this report describes the specific questions, equipment, and methods used in this research (including the development of a database which can be updated in real time by smartphone users). Chapter 3 outlines the results of the tests described in Chapter 2, including the differences between high-quality GPS units and smartphones as well as differences in performance in various urban environments. Chapter 4 discusses the implications of our results and recommendations for future research that is needed to improve these types of investigations.

Chapter 2. Equipment and Methods

2.1 Research Questions and Tests

This research explores three research questions through three specific tests. The three questions are:

1. What is the relative accuracy of standard smartphone and higher-quality, commercially available GPS routing programs?
2. How do various urban environments (e.g., urban canyons, bridges, or relatively open streets) affect the accuracy of route tracking data?
3. Are there differences in performance of smartphone GPS tracking devices among various manufacturers (e.g., LG vs. Motorola).

The associated tests are:

1. A comparison of the accuracy of the smartphone application (CycleTracks) GPS tracking system vs. a high-quality external GPS unit.
2. A comparison of the accuracy of GPS measurements in various urban environments (e.g., urban canyons vs. bridges or other open streets).
3. A comparison of smartphone performance among various manufacturers (e.g., LG vs. Motorola).

2.2 Integrating CycleTracks and External GPS Receiver

CycleTracks is a smartphone application available in Android and iPhone that records bicycle trip location and purpose for use in bicycle facilities management. The application uses the phone's internal GPS antenna to record the position of the bicyclist once per second. The application, which was developed by the San Francisco Transportation Authority, is open-source and can be downloaded and modified easily.

Smartphone GPS is sufficient for use in car navigation and other phone related activities; however, its accuracy is not sufficient for lane level positioning. Lane level positioning is of interest to bicycle facilities planners because it allows them to determine if specific bicycle facilities like bike lanes and bike boxes are being used. To obtain better location accuracy, a higher-quality external antenna was integrated into the CycleTracks Android application.

The BT-821 Bluetooth GPS receiver from GlobalSat was selected as the source for higher accuracy positions (Figure 2.1). The receiver has 32 parallel channels, a high capacity rechargeable battery, and is capable of receiving Wide Area Augmentation System (WAAS) corrections. The unit has a 23 hr battery specification, making it ideal for a bicycling application where the unit must operate without external power for a period of time.

Figure 2.1: The BT-821 Bluetooth receiver from GlobalSat.

The CycleTracks Android application was downloaded from its repository in github (https://github.com/sfcta/AndroidTracks). The phone software already reads from the phone's internal GPS, but needed to be modified to read from an external source. Software that employs the Android Bluetooth stack was written to connect to and read GPS NMEA 0183 sentences from the external unit. The NMEA sentences were parsed to extract the latitude, longitude and altitude positions. The status of the GPS solutions was also decoded so that it would be known if a solution was differentially corrected by WAAS.

The phone application stores trip data in a SQLite database resident on the phone while the GPS positions come in. The internal SQLite database was modified to accommodate information from the external GPS receiver. GPS positions coming from both sources were synchronized by the GPS time and inserted into the phone's database. At the end of the trip, the user selects to upload the trip data, and the data then are flushed from the phone database and sent to the web server via Javascript Object Notation (JSON).

The original phone source code contained the URL to the servers created by the San Francisco County Transportation Authority. Because the original database does not have the fields needed to accommodate the external GPS data, a web application was developed at the University of Minnesota. The Python based web framework Django was used to create the web Application Programming Interface (API) needed to communicate with the Android phone.

The web API included user management so that each phone could be associated with an anonymous user's phone with information entered in the app such as age and frequency of bicycling. Database tables and APIs were created to accommodate the extra data fields needed for the external GPS (Figure 2.2). The CycleTracks User and Trip models were left unchanged from the original application. The fields after the field "vac" in the Coordinate table (Figure 2) were added to the UofM version to accommodate data from the external GPS unit.

A web portal front end was developed to let the researchers visualize the bicycle trips for each user (Figure 2.3). The portal allowed entry of date ranges and selection of phone id. All trip routes for the selected phone and date range was displayed on a map. The GPS source, internal or external, could also be selected. This web portal was helpful for the researchers because they could verify that trip data was correctly being sent to the back end database.

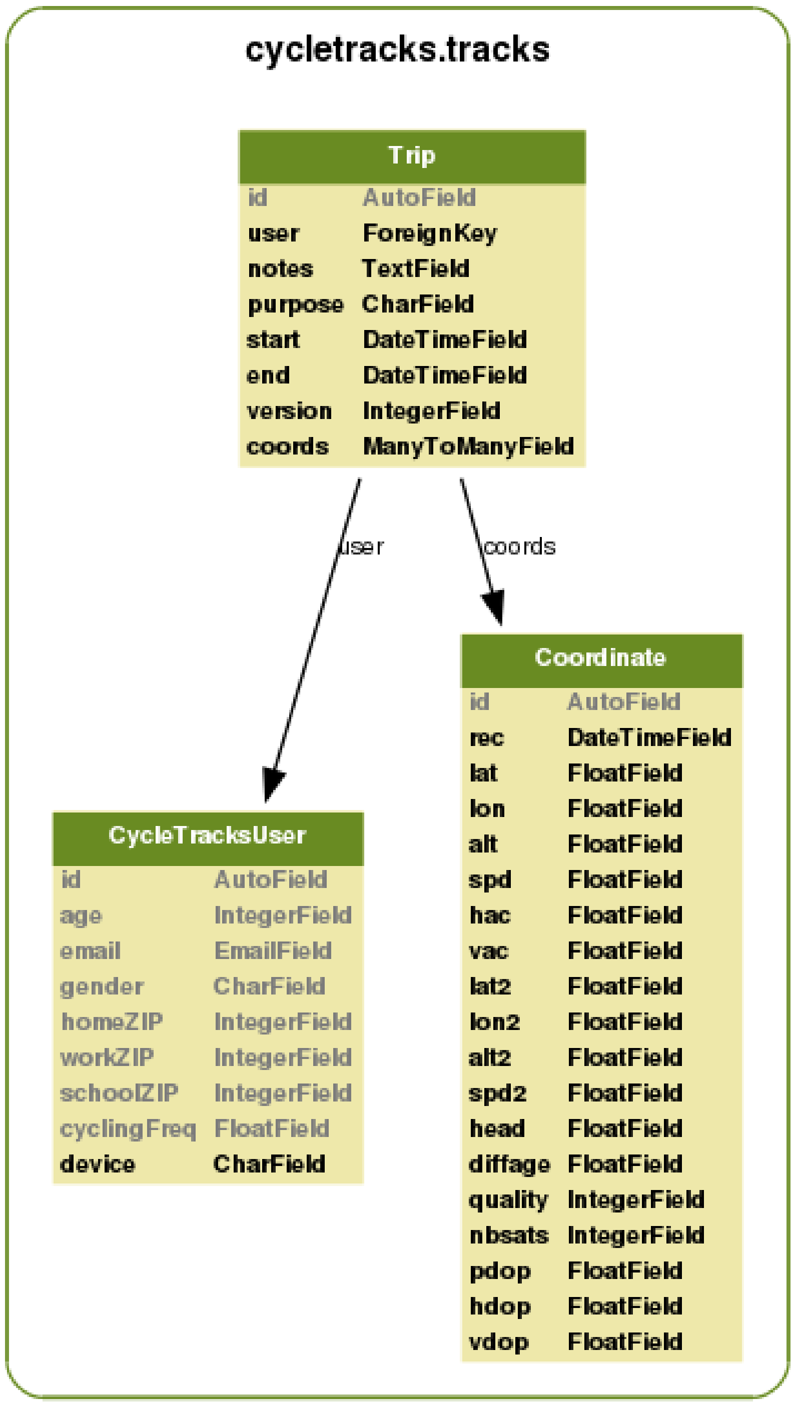

Figure 2.2: UMN CycleTracks back end server database model.

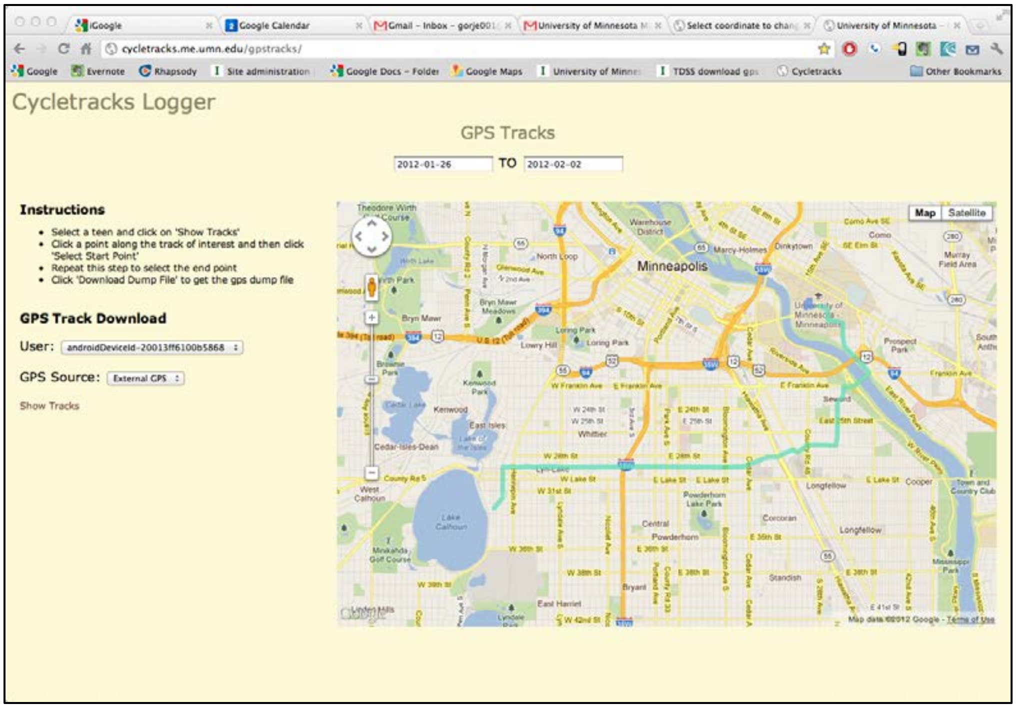

Figure 2.3: Screenshot of web portal showing trip recorded by external GPS receiver.

2.3 Corridors Used for GPS Field Tests

The research team chose four urban street corridors to compare the precision of CycleTracks GPS measurements and the external GPS receiver. The test routes were (Figure 2.4):

1. A bike lane on the Washington Avenue bridge over the Mississippi River that links the East and West Bank campuses of the University of Minnesota;
2. A bike lane on the West Bank campus of the University of Minnesota;
3. A bike lane on South 2nd Street in the central business district (CBD) in the city of Minneapolis; and
4. A traffic lane on Nicollet Mall, also in the central business district (CBD) in the city of Minneapolis.

These corridors were chosen because they reflect a range of built urban environments with characteristics that may impact GPS performance. The Washington Avenue Bridge corridor is open, with no tall buildings that might obstruct or interfere with GPS signals. The West Bank bike lane corridor was moderately open: it bisected a plaza lined by classroom buildings of varying height. The S. 2nd Street corridor also was moderately open, with low rise condominiums and commercial buildings adjacent to the street. Nicollet Mall, a relatively narrow, two lane street limited to bus, police, emergency, and bicycle traffic, is lined by tall, multi-story office buildings and is among the densest urban corridors in Minneapolis.

To compare the CycleTracks GPS measurements and the external GPS receiver, researchers cycled each corridor ten times while logging GPS points from both the smartphone (CycleTracks) and the external GPS. Each trip was cycled in the same direction with both the smartphone and external GPS mounted to the handlebars of each bicycle. GPS data were stored in servers as described in Section 2.2. Researchers then accessed the data, plotted routes relative to known positions on bike lanes, and performed a set of statistical tests to address the research questions.

2.4 Statistical Analyses

The research team performed three statistical tests to evaluate the performance of each GPS unit.

1. Test for differences between smartphone and external GPS performance. Using road centerline files provided by the City of Minneapolis, the team calculated mean distances between GPS measurements and the road centerline for each type of GPS unit. The team used a one-sided t-test to determine if there was a statistically significant difference between the smartphone (CycleTracks) and external GPS measurements.
2. Test for differences in GPS performance among test corridors. The team used analysis of variance (ANOVA) with and without contrasts to test whether there were differences in GPS performance by test corridor.
3. Test for differences in GPS performance among smartphone manufacturers. The team also used ANOVA to test for differences among smartphone brands.

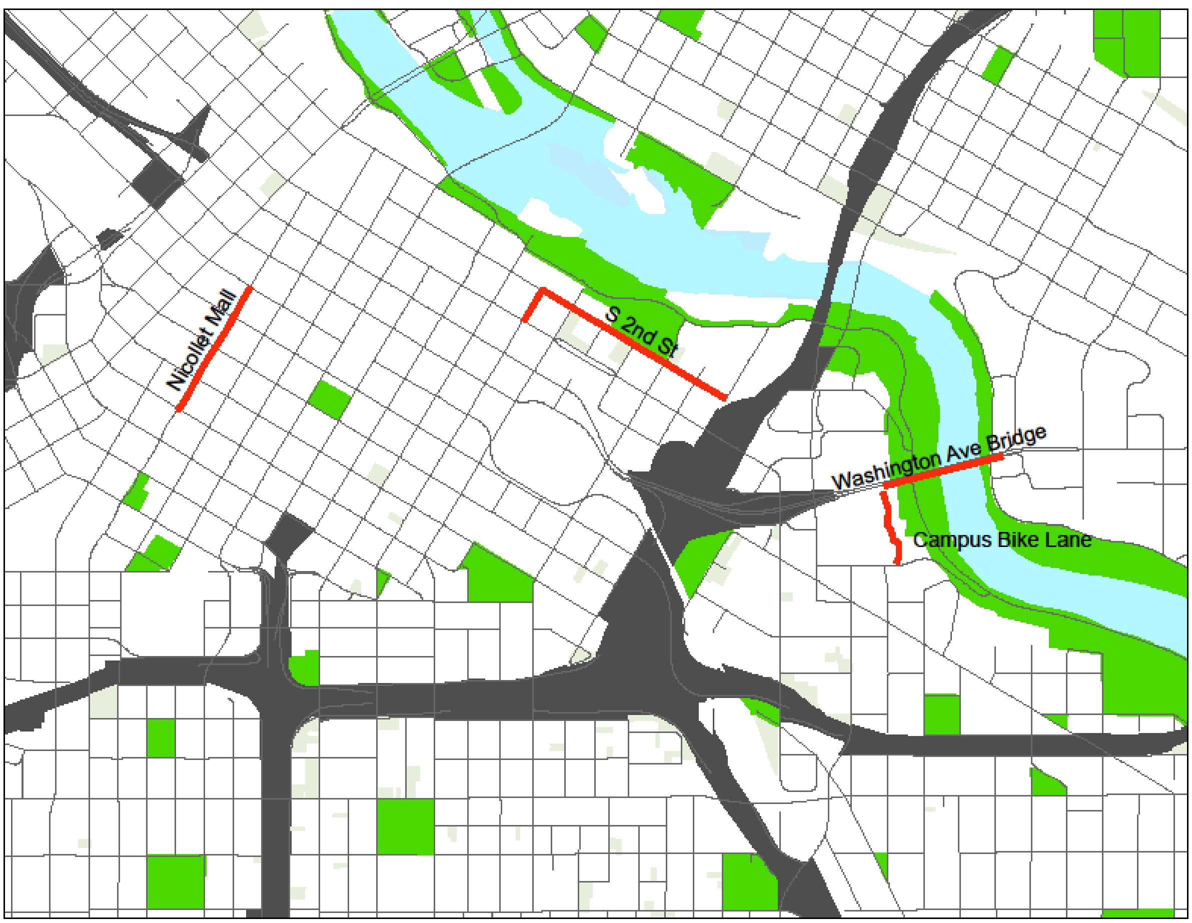

Figure 2.4: Test routes used to evaluate smartphone and external GPS performance.

Chapter 3. Results

3.1 Test Corridors and GPS Performance

The team was able to successfully implement the CycleTracks program in tandem with the external GPS receiver. Data from 40 corridor rides were uploaded to our servers and database. Riders had to repeat several trips because of human error in uploading or because of other minor malfunctions of the CycleTracks program.

After the rides were completed, the team extracted the relevant trips from the database and mapped each trip and the centerline of each test corridor. The purpose of this mapping exercise was to visually inspect and compare the relative performance of the smartphones and GPS receivers. Two illustrative maps are presented in Figure 3.1. Along the narrow Nicollet Avenue corridor lined by tall buildings, both the smartphone (blue lines) and external GPS (red lines) traces vary widely through the corridor and are frequently off the street. On the Washington Avenue bridge, the smart phone traces frequently extend off the bridge, while the external GPS traces are clustered nearer the centerline along the bridge. This simple mapping exercise illustrates that both the smartphone tracking and the external GPS have limitations with respect to tracking, although the external GPS tracks appear to be more accurate, especially in open areas with no adjacent tall building to obstruct or interfere with signals.

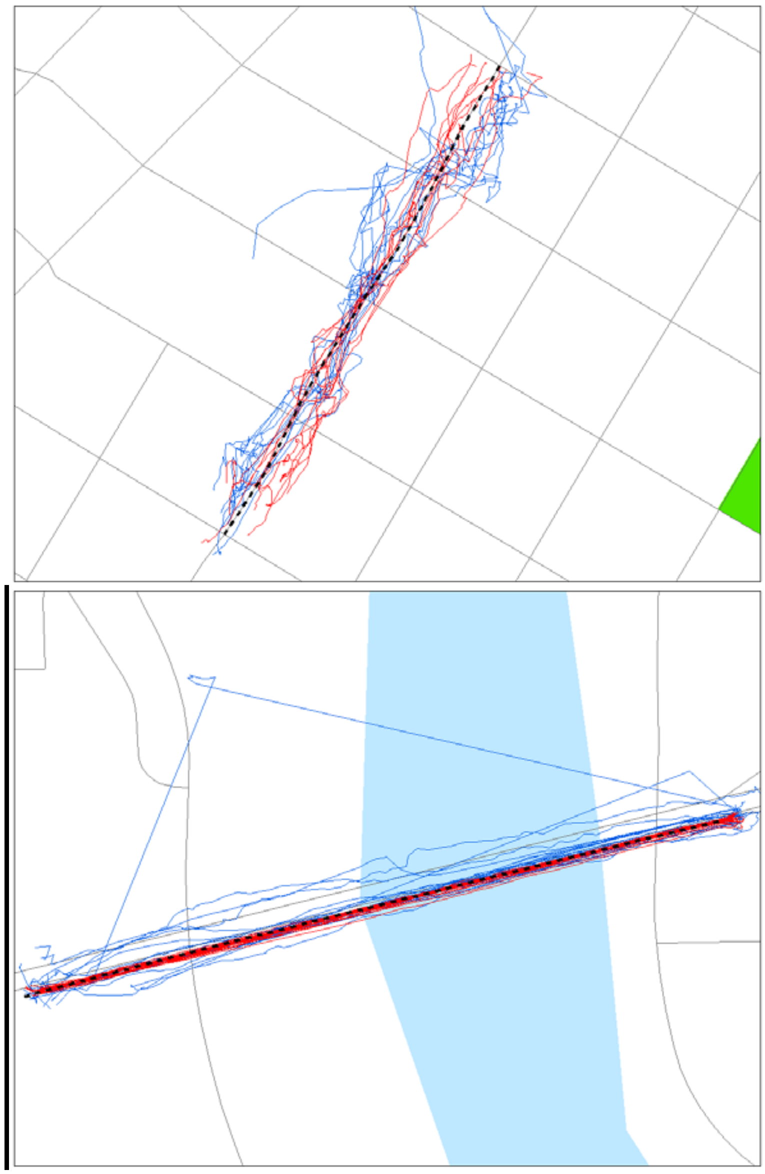

Figure 3.1: GPS route traces: Nicollet Mall (left panel) and Washington Avenue Bridge (right panel). Red lines show external GPS traces; blue lines show smartphone GPS traces. The dashed line shows the route centerline.

3.2 Smartphone CycleTracks vs. External GPS Performance

Statistical tests confirmed that the external GPS performed better than the smartphone (CycleTracks) GPS in each of the test corridors (Table 3.1). For the smartphone GPS, the mean distance from the centerline ranged from a minimum of 5.9 meters on the Washington Street bridge to more than 16 meters along Nicollet Mall. For the external GPS, the mean distances from the centerline varied similarly across locations, though the mean distances were smaller, ranging from 1.8 meters on the Washington Avenue Bridge to more than 11 meters along Nicollet Mall. Across the four locations, the mean difference between the traces and the center line for the smartphone GPS was twice that of the external GPS. Statistical tests (one-tailed) confirmed that the differences were significant (at the 1% level for three of the corridors and at the five percent level for the S. Second Street corridor). In sum, as measured by distance from centerline, the route traces for the external GPS were more accurate.

Table 3.1: Mean differences between GPS traces and corridor centerlines.

Bike Lane Corridor	**Smartphone GPS** (meters from centerline)	**External GPS** (meters from centerline)	Difference between GPS units (meters)
Nicollet Mall	16.27	11.43	4.84 **
S. Second St.	11.86	5.01	6.84 *
West Bank bike lane	7.87	2.75	5.12 **
Washington Ave. bridge	5.86	1.76	2.94 **
All locations	9.54	4.54	5.00 **
* denotes statistically significant differences (one-sided paired t-test) ($p < 0.1$). ** denotes statistically significant differences (one-sided paired t-test) ($p < 0.05$).			

3.3 Differences in GPS Performance by Route

To test for differences in GPS accuracy across corridors, the researchers performed an ANOVA analysis using contrasts (Tables 3.2 and 3.3). This approach allows for testing of particular patterns among means of data of interest. The analyses of contrasts were completed using the R statistical program. With one exception, these tests confirmed that the performance of the GPS units is significantly associated with the character of the built urban environment. Specific findings include:

- No significant differences in accuracy between the Washington Avenue Bridge (most accurate) and the West Bank campus bike lane (second most accurate) corridors;
- A significant difference between the Washington Avenue Bridge and S. Second Street corridors (third most accurate); and
- A significant difference between the Washington Avenue Bridge and Nicollet Mall (i.e., the least accurate) corridors.

Table 3.2: ANOVA Results: Test of Differences in GPS Accuracy across Corridors.

	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability (>F)
GPS	1	567.4	567.4	18.4543	5.431e-05***
Location	3	1235.37	411.79	13.3932	5.094e-07***
Smartphone	1	146.41	146.41	4.7619	0.03241*
GPS:location	3	16.31	5.44	0.1768	0.91178
Residuals	71	2182.98	30.75		
*Significant at the 0.05 level ***Significant at the 0.001 level					

Table 3.3: ANOVA results: Analysis using contrasts (R output).

>fit.contrast (m1,varname="loc", coef=c (1,-1,0,0)) # no difference bridge vs cam$				
	Estimate	Std. Error	t value	Pr(>|t|)
loc c=(1 -1 0 0)	-2.13234	2.479767	-0.8598953	0.392741
> fit.contrast (m1,varname="loc", coef=c (1,0,-1,0)) # bridge better than 2nd				
loc c=(1 0 -1 0)	-6.11566	2.979767	-2.466224	0.01607133
> fit.contrast (m1,varname="loc", coef=c (1,0,0,-1)) # bridge better than nicollet$				
loc c=(1 0 0 -1)	-10.53275	2.479767	-4.247476	6.452523e-05
> fit.contrast (m1,varname="loc", coef=c (0,0,1,-1)) #				
loc c=(0 0 1 -1)	-4.41709	2.979767	-1.781252	0.07914825

3.4 Differences in GPS Performance by Smartphone Manufacturer

To ensure that differences between smartphone and external GPS units and differences across locations were not affected by variation in accuracy of GPS units in smartphones, we also performed statistical tests across smartphones. These tests also were conducted using ANOVA. Statistical tests indicated no significant differences among smartphones (Table 4). These results indicate that the finding of significant differences between the smartphone GPS traces and the external GPS traces are not associated with differences among individual smartphones.

Table 3.4: ANOVA results: Tests for differences among smartphones.

	Analysis of Variance				
	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability (>F)
Phone	3	96.83	32.276	2.1302	0.11399
GPS	1	167.87	167.868	11.090795	0.002063**
Residuals	35	530.29	15.151		
**Significant at the 0.01 level					

Chapter 4. Discussion and Implications for Future Research

Researchers have shown that the provision of bike lanes and other bike facilities can increase bicycle volumes and decrease potentially dangerous interactions between vehicles and bicycles. Researchers also have shown that GPS units in smartphones can be used to identify routes taken by cyclists, including whether cyclists deviate from shortest paths to use bike lanes and other facilities. Researchers previously have not reported whether GPS tracking can be used to monitor whether and how bicyclists actually use lanes on streets, where these lanes have been provided, or other types of facilities. For example, when bike lanes have been striped on a road, little is known about the relative proportions of cyclists who ride in the vehicular lanes, the bike lanes, or parking lanes. This type of information is important when assessing the likelihood that bike lanes will increase safety of both vehicular and bicycle traffic. The objective of this research was to determine whether smartphone GPS units or enhanced GPS units could be used to track and map the location of cyclists on streets.

4.1 Use of GPS to Monitor Cyclists' Use of Bike Facilities

Our investigation suggests that neither smartphone GPS units nor higher-quality external GPS units generate data accurate enough to monitor whether and how cyclists use bicycle facilities. Although data from commercially available GPS units can be used to determine routes taken by cyclists, and therefore to infer use of some facilities, the resolution or accuracy of the data is not sufficient to assess how facilities are used. For example, the mean difference in smartphone measurements from the centerlines across the four locations was 9.54 meters, or a little over 31 feet. Given this variability in measurement across locations and the fact that the minimum width of a bike lane is only five feet, the lack of feasibility of measuring lane usage is obvious.

The quality of data obtained from both the smartphone GPS and the external GPS unit varied with the general characteristics of the built urban environment. Data quality was highest in open areas where tall buildings did not obstruct or interfere with GPS signals, and data accuracy was significantly worse in the corridor lined by taller commercial office buildings. Higher-quality external GPS receivers generated data that are significantly more accurate, but at this time they also remain inadequate for determination of lane positioning. Without advancements in GPS technology, investigations of cyclists' use of bicycle facilities may need to rely on other technologies such as inductive loops placed in streets and bike lanes or video tapes of traffic with either automated or manual classification.

4.2 Future areas of Research

Future areas of research include both study of new GPS technologies that might support tracking of lane positions and identification of strategies for using currently available GPS data in other types of safety-related studies. As GPS technologies continue to improve, consumer demand grows, and scales of economy in production increase, improved devices may come onto the market, enabling the type of application explored in this study.

In the interim, novel uses of GPS route data may enable researchers to make additional inferences about behaviors of cyclists that have implications for the design of safety measures. Studies comparable to those completed by the San Francisco County Transportation Authority that document the propensity of cyclists to deviate from shortest-routes to ride on streets with bike facilities could be replicated. This type of research, which indicates that cyclists are willing to spend time and exert additional energy to increase perceptions of safety, is important for management decisions such as spacing of lanes in street networks. Similarly, analyses of crowd-sourced route data could yield insights into the propensity of cyclists to ride on or avoid streets with high vehicular traffic.

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